THE EFFECTS OF PINEAPPLE RESIDUE ("TRASH")

ON N MINERALIZATION AND EARLY GROWTH OF PINEAPPLE

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN AGRONOMY AND SOIL SCIENCE

MAY 1981

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ACKNOWLEDGEMENT

The First Letter to Timothy in the New Testament bears the following statement:

> This is a faithful saying, and worthy of all acceptation, that Christ Jesus came into the world to save sinners.

I present the statement here as a personal reminder of God's help toward the completion of all the major and minor areas of the program represented by this dissertation.

ABSTRACT

Although limited studies by the Pineapple Research Institute of Hawaii indicated that mineralized N in the soil during a 3-year pineapple cycle represented a significant amount of available N to the crop, the effects of crop residue management on available N in pineapple soils have not been clearly determined. The studies presented here were undertaken to evaluate the effects of incorporated pineapple plant residue on soil N mineralization and on early growth of pineapple with different applications of NH_4NO_3.

Soil N mineralization during incubation in the laboratory was studied for four different pineapple soils from Central Oahu, Hawaii. The soils were incubated with and without 1.0% residue containing 1.0% N. Mineralization was linear with time between 30 to 210 days of incubation in those soils without residue treatment. After 30 days of incubation, soils treated with 1.0% residue had a deficit of 9 to 61 ppm mineral N relative to untreated soil samples. Following the initial residue-induced N immobilization period, an increased rate of mineralization compensated for the immobilized N.

Pineapple was grown in the glasshouse in two experiments of identical design for 4 and 10 months. The same four soils that were used in the incubation experiment were prepared for planting with 0.0 and 1.0% residue and 0 and 100 ppm N applied to the soil as NH_4NO_3. The plants were grown with and without foliar applied NH_4NO_3. All treatments were superimposed in a complete factorial

design. During the 4-month interval after planting, plant growth appeared to be more closely related to the structure, moisture-holding characteristics, and base status of the soils than to the N regime. While residue incorporation significantly reduced the amount of available soil N during this initial 4-month interval, it significantly improved the soil-plant moisture status and resulted in significant increases in plant dry weights. For plants harvested 10 months after planting, both the initial levels of soil NO_3-N, ranging from 15 to 105 ppm, and the amount of N applied to the soil or the leaves were major determinants of plant N uptake and plant growth. Residue incorporation reduced the final N uptake from the soil at 10 months, but by small amounts and only for soils having 105 ppm initial NO_3-N or 100 ppm applied soil N.

There was no correlation between N uptake in the glasshouse and N mineralized in the laboratory. In both the 4- and 10-month glasshouse experiments the application of NH_4NO_3 to the soil tended to be superior to its application to the leaves as far as plant dry weights were concerned. There was no evidence in these studies that the removal or incorporation of pineapple residue has any direct effect on the N regime during a pineapple cropping cycle in Hawaii.

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Chapter I

INTRODUCTION

A pineapple cycle in Hawaii consists of two to three crops grown over a period of approximately three to four years. The pineapple plant residue at the end of the cycle, referred to as pineapple "trash" by the industry, is presently handled in one of three ways:

1) Burning to facilitate the early planting of the next cycle;
2) Mechanical harvesting for alternative uses such as animal feed;
3) Incorporation into the soil where sufficient time exists for decomposition prior to planting the next cycle.

Recent analyses made at the University of Hawaii (by this author) and unpublished analyses at the Pineapple Research Institute of Hawaii indicate that roughly 500 kg K, 400 kg N, 250 kg Ca, 100 kg Mg and 50 kg P per hectare are normally present in the residue. There is a tendency to assume that the respective quantities of each nutrient are potentially available to the subsequent crop if the residue is incorporated into the soil. While this assumption has a sound basis for K, owing to its release from the residue in water soluble form and its retention in the soil by cation exchange, the assumption is seriously in error in the case of N, which is microbially assimilated during residue decomposition and hence not directly released into the soil solution.

Because K and N are the fertilizer elements which are applied in the greatest quantity to pineapple, an accurate assessment of their

recycled fertilizer value is important to the industry, particularly where residue must be evaluated on an incorporation versus removal basis. Research by Tam and Magistad (1936) at the Pineapple Research Institute helps to substantiate the assumption that residue K is the logical equivalent of fertilizer K when incorporated into the soil. However, an accurate evaluation of residue management in terms of fertilizer N has not been made. This becomes increasingly necessary as the cost of N fertilizers rises to the level of other high-cost management practices.

The objective of the present experiments was to make a quantitative assessment of pineapple residue in different soils based on (1) N mineralization in the laboratory and (2) plant response to applied N in the glasshouse.

Chapter II

BACKGROUND AND LITERATURE REVIEW

II.A. SOIL NITROGEN

More than 95% of the total N in soils, excluding gaseous N, is in organic forms unavailable for plant growth. Hawaiian pineapple soils typically range in organic N content from about 0.1 to 0.5% (Soil Conservation Service, 1976), or the equivalent of 2,000 to 10,000 kg/N/ha in the surface (2×10^6 kg/ha) soil. In contrast, mineral N (i.e., inorganic forms of soluble N) in the soil solution normally fluctuates between 5 and 50 ppm or 10 and 100 kg/ha, depending upon the soil and the environmental conditions.

II.A.1. The N Mineralization Cycle

The microbial release of mineral N is a net result of two processes--N mineralization and N immobilization. The mineralization of N is the conversion of N from an organic form to a mineral form. The overall conversion entails a host of microbial agents and organic substrates. The immobilization of N is the microbial assimilation of mineral N into organic compounds. It is important to understand that N is neither added to nor removed from the rhizosphere by either process, but is cycled between the large organic fraction and the small mineral fraction. Recent comprehensive discussions and literature reviews regarding the N mineralization cycle in soils include those by Bartholomew (1965), Allison (1966; 1973), and Campbell (1978). An earlier review by Harmsen and Van Schreven (1955) and

the elementary discussion and brief literature review by Black (1965) are hallmarks.

Losses of N from the N mineralization cycle occur by (1) the conversion of organic N into relatively stable forms which are resistant to mineralization, (2) the fixation of ammonium cations by clay minerals, and (3) the removal of mineral N from the rhizosphere by plant uptake, leaching, and denitrification. It is the usual case in aerated soils for NH_4-N to be nitrified as quickly as it is produced (Harmsen and Van Schreven, 1955). Thus, NO_3-N is logically considered to be the end product of N mineralization. The nitrate anion assumes a major role in N loss from aerated soils because it is repelled from cation exchange sites and is therefore highly susceptible to leaching. However, since NO_3-N is a substrate for microbial assimilation (i.e., N immobilization), it is not lost from the N mineralization cycle until it is actually leached or otherwise removed from the rhizosphere.

II.A.2. Mineralizable N and Available N

The quantity of N mineralized is dependent upon the quantity and nature of a poorly understood organic matter fraction referred to as mineralizable N. The quantity of mineralizable N in a soil cannot be accurately determined. Research by Winsor (1958) and by Keeney and Bremner (1964; 1966a) clearly indicated that the mineralizable N substrates in a given soil vary in their resistance to mineralization. Moreover, others (Harmsen and Van Schreven, 1955; Bremner, 1965; Robinson, 1975) concluded that mineralizable N is affected by sampling, storage and laboratory handling of the soil.

Conceptually, "available N" might be defined as the sum of three components: (1) The mineral N initially present in the soil solution; (2) the additional N released by N mineralization; (3) the mineral N added as fertilizer. It is clear from this concept of "available N" that routine soil tests for N suffer in situations where mineralizable N becomes an important determinant because in the first place mineralizable N cannot be accurately determined by soil testing and in the second place N mineralization in the field depends upon a host of environmental factors. Mineralizable N in different soils has been related to the N uptake of crops such as corn in Iowa (Fitts, et al., 1953), wheat in Saskatchewan (Cook, et al., 1957), sugar cane in Hawaii (Stanford, et al., 1965), and sugar beets in Utah (Carter, et al., 1974). It has been carefully pointed out in reviews and discussions of soil testing for "available N" (Bremner, 1965; Dahnke and Vasey, 1973; Robinson, 1975; James, 1978) that where other factors are not limiting, both the recovery of fertilizer N from the soil and the crop response to fertilizer N are inversely related to the mineral N level in the soil at the time of planting and the net N mineralized during the cropping season. Unfortunately, much of the fertilizer N research has been restricted to response experiments involving applied N while the influence of mineralized N is not evaluated.

Both chemical and biological procedures have been developed to study mineralizable N in soils. Chemical procedures have usually entailed the extraction of NH_4-N by partial digestion and hydrolysis of relatively small fractions of the total organic N. Extraction

solutions for so-called "chemical tests" include 1.0 N $Ba(OH)_2$ (Jenkinson, 1968), 1.0 N NaOH (Cornfield, 1960), 8% H_2SO_4 (Purvis and Leo, 1961), 0.01 M $NaHCO_3$ (Fox and Piekielek, 1978), hot 0.01 M $CaCl_2$ (Smith and Stanford, 1971), acid 0.1 N $KMnO_4$ (Stanford and Smith, 1978) and alkali $KMnO_4$ of varying concentrations (Stanford, 1978). This list of extractants is by no means complete and the procedures reported are as often modified as they are exactly repeated. Regardless of the chemical method employed, its relationship to mineralizable N is not well understood.

Biological procedures for studying mineralizable N in soils generally entail incubation under standardized conditions followed by mineral N extraction. The quantity of mineral N produced during incubation is the basis for a mineralization index which can be expressed as a mineralization rate, as cumulative N mineralized, or in some other fashion. The so-called "biological tests" described in the literature differ in quantity of soil, soil preparation, incubation amendments, incubation vessels, temperature and moisture controls, gas exchange, and mineral N extraction. A partial explanation for the diversity of procedures is that optimum conditions for N mineralization are not well understood. Studies of moisture (Miller and Johnson, 1964; Stanford and Epstein, 1974) and temperature (Harmsen and Kolenbrander, 1965; Stanford, et al., 1973) indicate that tensions of 10 to 30 cm Hg and temperatures near 35°C are optimum; however, enhanced N mineralization rates owing to alternating moist-dry conditions (Agarwal, et al., 1971) and interactions between temperature and moisture in the near optimum regimes

(Cassman and Munns, 1980) have been reported. Harmsen and Van Schreven (1955) and Robinson (1975) pointed out that optimum incubation conditions probably vary among soils and noted that the correlations between N uptake and mineralization index are often improved by segregating soils, particularly according to textural characteristics.

Chemical and biological tests for mineralizable N are commonly evaluated by determining their correlation with N uptake by plants under glasshouse conditions. Where several chemical and biological tests have been simultaneously evaluated for widely different soils (Keeney and Bremner, 1966b; Jenkinson, 1968; Robinson, 1968; Stanford and Legg, 1968; Lathwell, et al., 1972), biological tests involving aerobic incubation for 2 weeks or more were more highly correlated with N uptake than chemical tests. An explanation for this general finding was offered by Keeney and Bremner (1966b) who studied the changes in different organic N fractions during the incubation of soils from 26 sites. Keeney and Bremner (1966a) concluded that soils differ with regard to the nature of the N that is sensitive to the extracting solution. Keeney and Bremner (1966a) further concluded that chemical tests cannot estimate mineralizable N as reliably as aerobic incubation tests.

II.A.3. Soil Comparisons by Incubation Methods

Unlike physical and chemical indexes of soil parameters such as texture, exchangeable cations, total N, pH, etc., laboratory-derived mineralization indexes are only indirectly related to mineralizable N, and hence to available N in the field. Nevertheless, laboratory-

derived mineralization indexes have been successfully used to help characterize field soils which differ in management history, location, and classification. Four such studies (Allison and Sterling, 1949; Stanford, et al., 1965; Stanford and Smith, 1972; Ingamells and Sanford, 1979) are discussed below in order to specifically point out how intrinsic mineralization differences were proven to be important. Some attention is called to the variety in the methodology since the transfer of information in soil N research is limited in this regard.

Allison and Sterling (1949) incubated soil from a single site which was subjected to various cultural and cropping treatments for 33 years. Their procedure entailed the maintenance of soil with and without 1% $CaCO_3$ at 20% moisture and 28°C for periods ranging from 21 to 186 days. The net N mineralized was curvilinear and the decline in the apparent N mineralization rates was much greater in soils with a low total N content. While net N mineralized was inversely related to total N losses associated with management history, the correlations with total N ranged from $r^2 = 0.30$ to 0.80, depending upon the incubation period and the $CaCO_3$ treatment. For incubation periods of 161 and 186 days, the cumulative N mineralized ranged from 3 to 15% of the total soil N and was somewhat dependent upon the levels of exchangeable bases.

Stanford, et al. (1965) derived a mineralization index for Hawaiian sugar cane soils by incubating the soils for 2 weeks at 29°C. Neither the mineralization index nor N uptake by sugar cane in the field correlated with total N. Close relationships among the

mineralization index, N uptake, and cane yield enabled the authors to predict N fertilizer requirements based on the mineralization index. Recalculating the reported values, the net N mineralized in the laboratory ranged from 1 to 3% of the total N.

Stanford and Smith (1972) compared 39 soils differing in location, classification, chemical characteristics, and management history by using a serial leaching procedure over a 30-week incubation period at 35°C. A consistent linear relationship between the net N mineralized and the square root of time was observed, which enabled the authors to estimate "potentially" mineralizable N. The mineralization curves as a function of time showed even small differences among soils. Using regression methods, Stanford and Smith (1972) estimated values of "potentially" mineralizable N which ranged from 20 to over 300 ppm and represented 5 to 40% of the total N, depending upon the soil.

Ingamells and Sanford (1979) used an incubation approach similar to the one of Stanford and Smith (1972) in order to compare Hawaiian pineapple, sugar cane, and uncultivated soils of corresponding classifications from a total of 48 sites. The soil characteristics and mineralization data are reported in Appendix A. The following represents an updated and more conclusive summary of the results presented by Ingamells and Sanford (1979):

The net N mineralized in the laboratory was linear in time from 16 to 196 days incubation. The linear release was not affected by the duration of the period between leachings in the range of 12 to 52 days. This result suggested that the mineralization rate was a

good mineralization index for these soils, provided initial lags or bursts of N mineralization were accounted for. It was concluded that among the soils studied, management history and not classification was the principal determinant of differences in mineralizable N. Pineapple soils had the lowest mineralization index values, sugar cane soils had slightly higher values, and uncultivated soils had the highest values. Total N did not correlate well with the linear mineralization rate or the net N mineralized, and the correlations were especially poor within each of the three management categories. The net N mineralized at 196 days ranged from 1 to 6% of the total N in respective pineapple soils, 3 to 6% of the total N in respective sugar cane soils, and 2 to 9% of the total N in respective uncultivated soils.

All of the four studies just cited demonstrated that mineralization indexes reflect intrinsic N release characteristics. A carefully derived index allows a precise comparision of different soils, even though the intrinsic mineralization characteristics are poorly understood or unidentified. Mineralized N was consistently only a small fraction of the total N and in none of the studies could an explanation be offered for the observed variations in proportion of soil N susceptible to mineralization. No single intrinsic property (e.g., total N, base saturation) was identified that was consistently well related to a mineralization index. Together, the results strongly imply that N availability research conducted in different soils should not ignore the intrinsic mineralization differences and should include a mineralization index in the soil characteristics data.

The unfortunate situation in soil N research is that a single standardized procedure for deriving a mineralization index has not been adopted which will allow a comparison of separately published results. As a consequence, interesting differences among soils of different geographical regimes are likely unrecognized. The prolonged linear release of mineral N reported for Hawaiian soils by Ingamells and Sanford (1979) is an example which stands in sharp contrast to the curvilinear release reported for Continental U. S. soils by Allison and Sterling (1949) and Stanford and Smith (1972). Differences in management history, classification, texture, pH and C:N ratio were great enough between the Hawaiian and the Continental soils to suggest that differences in mineralization were an accurate reflection of different intrinsic soil properties, and not merely the result of differences in procedure.

It is a reasonable conclusion that the linear N release during incubation for the Hawaiian soils discussed above was due either to (1) the stability of the most readily mineralizable substrates or (2) the replacement of mineralizable N by the microbial or chemical transformation of other organic N constituents. Both possibilities (i.e., stability and replacement) have been acknowledged to be important processes (Harmsen and Van Schreven, 1955; Stanford and Smith, 1972; Campbell, 1978), but they have not been well researched. For tropical soils, Kanehiro (1978) has cited the evidence of several researchers that allophane and amorphous hydroxides impede soil microbial activity and impart a certain degree of stability to organic N fractions. Regarding the replacement of mineral N,

Keeney and Bremner (1964; 1966a) concluded from their incubation studies that there is a tendency for soils to maintain rather constant proportions of several different organic N fractions of varying resistance to mineralization.

II.A.4. Available N in Hawaiian Pineapple Soils

The total N utilized by pineapple in a 3-year cycle may range from 450 kg/ha upward (Smith, 1961a). A large percentage of this N is taken up by the crop during the several months of growth prior to the floral initiation of the first crop, which is normally 10 to 14 months after planting (Sanford, 1961). Apparently no work has been conducted to determine the fraction of plant N obtained by the crop from mineralized soil N. One reason little attention has been given to mineralized N is that rates of foliar N application usually range in the neighborhood of the 450 kg/ha N requirement, thus overshadowing the fractional contribution of either native soil N or applied soil N.

Studies of available N in Hawaiian pineapple soils indicate that N mineralization in the field is at least appreciable, although probably less than the rates of fertilizer N application. Magistad (1932) estimated that 100 to 200 kg N/ha/year was mineralized in the surface soil of fallow pineapple fields depending upon the location. Fukunaga and Dean (1939) found that four pineapple soils mineralized 25, 58, 62, and 170 ppm N after 37 weeks incubation.

A number of environmental and management factors which are especially important to pineapple production have been reported to affect N mineralization and N availability in field soils elsewhere.

As examples: Fallowing between cycles has been shown to enhance mineralization relative to continuous cropping (Goring and Clark, 1948). Increasing moisture tensions until the region of the wilting point have been inversely related to N mineralization rates (Robinson, 1957). The frequency and magnitude of wet-dry cycles have been shown to be proportional to annual mineralization rates (Semb and Robinson, 1969). At optimum moisture, Q_{10} values near 2.0 have been determined (Stanford, et al., 1973). Tillage has been shown to temporarily enhance mineralization (Dowdell and Cannell, 1975). As a final example of relative importance to the pineapple industry, various soil fumigants used for nematode control have been reported to have a variety of positive, negative, or insignificant effects on N mineralization and N uptake (Davidson and Thiegs, 1966; Englerth, 1969).

More work needs to be done to obtain reliable estimates of N mineralization in field soils of Hawaiian pineapple plantations. Without this work, it is virtually impossible to assess the effects on available soil N resulting from various management or environmental factors such as those mentioned above and particularly those effects which are due to pineapple residue and intercycle management schemes.

II.B. RESIDUE MANAGEMENT

In forests, grasslands, and in a number of other cropping systems, large quantities of N are recycled during residue decomposition (Jenney, et al., 1949; Nye and Greenland, 1960). Laboratory studies of the effects of specific plant residues, such as sawdust

(Allison and Cover, 1960), vegetable crops (Iritani and Arnold, 1960) and grain straw (Pinck, et al., 1946), have been conducted in conjunction with glasshouse studies of N uptake in order to derive quantitative relationships between residue N concentration and net N mineralization.

II.B.1. Effects of Crop Residues on the N Mineralization Cycle

The C:N ratio (or, alternatively, the N concentration) of soil incorporated plant residue determines whether N mineralization or N immobilization is enhanced with respect to soils without residue incorporation. Thus, N availability increases following green manuring with a crop having a low C:N ratio in the range of approximately 10:1 or 3 to 4% N (Hoover, 1942; Bremner and Shaw, 1957) and temporarily decreases following the incorporation of straw or stover with a high C:N ratio of approximately 50:1 or 0.5% N (Stojanovic and Broadbent, 1956; Parket, et al., 1957). Harmsen and Kolenbrander (1965) noted that critical residue C:N ratios (i.e., the ratio above which measurable N immobilization takes place upon incorporation) may vary between 15:1 and 30:1. According to Black (1968), where N concentration has been the alternative expression, critical residue N concentrations have been reported to range from 1.2 to 2.6% on a dry weight basis. The wide range is no doubt due to the diversity of soils and residues studied as well as the diversity of methods used, particularly with regard to the quantity of residue incorporated and the length of incubation following residue incorporation (Waksman, 1924; Jensen, 1929; Iritani and Arnold, 1960; Enwezor, 1976).

Residue decomposition rates, and associated N mineralization processes, depend upon the quantity and nature of the undecomposed substrate. Jenkinson (1965) identified two distinct stages in the decomposition of ryegrass residue in an incubated soil. Two thirds of the carbon from the residue was lost during the first 6 months, after which the decomposition rate was 16% per year. The decomposition rate of the soil humus was 2.7% per year.

According to Bartholomew (1965) plant residue N is readily available to microorganisms upon addition to the soil and only a certain fraction of the residue N that is incorporated can be expected to be released as mineral N. Later studies by Broadbent and Nakashima (1967), Stanford, et al. (1970), and Legg, et al. (1971) showed that as much as 50% of the ^{15}N incorporated both as residue and in mineral forms was transformed into stable organic N fractions in the soil.

Closely related to the above findings is the poor recovery of mineral N from soils owing to those N immobilizations which are not necessarily the result of residue incorporation. Gasser (1961) reported that the N recovery of ryegrass grown in the glasshouse with no residue incorporation averaged two thirds of the mineral N applied. Pinck, et al., (1946) reported that less than 60% of the applied mineral N was recovered by plants grown in the glasshouse, the balance being immobilized indefinitely owing only partially to the incorporation of straw prior to planting.

II.B.2. Available N Following Pineapple Residue Incorporation

Pineapple plants at the time of fruit harvest rarely exceed 1.0% N on a total dry weight basis. Upon incorporation into the soil, the immobilization of free mineral N would be expected. The immediate and complete immobilization free mineral N during the incubation of residue treated soil in the laboratory has been demonstrated for a Molokai soil by Asghar and Kanehiro (1976) and by Ingamells and Sanford (1979) for each of 48 Hawaiian soils (Appendix 1). In the latter study, ground pineapple plant residue containing 1.0% N was mixed with the soil at the rate of 1.0%. A leaching just prior to incubation removed all the mineral N initially present. The net N mineralized was zero in the residue treated soils for periods ranging from less than 16 to more than 100 days, which corresponded to the third and sixth serial leachings, respectively. Enhanced N mineralization followed N immobilization and ranged from one to two times the rates for the same soils without residue. The enhanced rates were indicative of the energy supplied by the residue for microbial activity and the narrowing of the residue C:N ratio during decomposition.

During a 35-week field study of 54,000 kg/ha incorporated pineapple plant residue containing 0.7% N (Tam and Magistad, 1936), mineral N reportedly never dropped below 20 ppm in the surface 30 cm and increased steadily from 20 ppm at 23 weeks to 37 ppm at 35 weeks. Tam and Magistad (1936) concluded that the mineral N was not completely immobilized because of the low C:N ratio (5.2:1) of the surface soil. Rapid decomposition occurred from week 12 to week 20

and coincided with a period of high rainfall. At 12 weeks, 80% of the initially incorporated residue remained undecomposed, while 20% remained at 20 weeks. Fluctuations in mineral N levels in the soil from 0 to 20 weeks could not be explained but were likely related to the accumulation of mineralized native soil N and the low soil moisture and slow decomposition rates of the first 12 weeks.

Work has been done to show that incorporating green manures may effectively enhance N mineralization in pineapple soils. For example, Magistad (1932) reported that pigeon pea residue increased leaching losses of NO_3-N by 1.8 to 2.3 times under fallow conditions. Work has also been done to show that growing and incorporating grass in pineapple soils may increase N mineralization after sufficient periods of decomposition. King (1934) showed that panicum growth and incorporation resulted in increased rates of NO_3-N accumulation and greater N uptake rates by pineapple during the second year following incorporation. In the same study, King (1934) showed that the decomposition of incorporated pineapple residue had little if any effect on available N except where pineapple residue was incorporated prior to planting panicum, in which case the positive effect of the later incorporation of panicum on available N was enhanced. Together, the above studies (Magistad, 1932; King, 1934; Tam and Magistad, 1936) indicated that a grass or legume grown and incorporated prior to replanting pineapple was of greater value to N mineralization in field soils than pineapple residue incorporation. Thus, grasses and legumes were recognized early in the history of pineapple production in Hawaii to be of significant value in

intercycle management, and various grass or legume species were sometimes tested in the field for yield and amendment qualities (Magistad, et al., 1934; Tam, 1943a).

II.B.3. Uncertainties of Pineapple Residue Evaluations

The complexities of evaluating N availability in relation to pineapple residue management are implied by the contrasting results of field and container experiments. The field studies cited above indicated marginal if any effects of pineapple residue incorporation on N availability, while Tam (1937) reported significant increases in extractable N owing to pineapple residue incorporation in large containers. Similarly for plant growth and fruit yield, pineapple residue incorporation has been shown to have virtually no effect in field experiments (King, 1934; Tam, 1943b) but some positive effect in container experiments (Tam, 1937; Tam, et al., 1942; Tam, 1944).

There are probably two general reasons for the contrasting results between field and container experiments. First, fluctuations in N availability are largely the result of the dynamic nature of the N cycle which puts N in contrast with other macronutrients such as potassium. This is evident in the pineapple residue study of Tam and Magistad (1936) where, during residue decomposition in the field, fluctuations in extractable N could not be accounted for while increases in extractable K from 0.31 meq/100g to 1.03 meq/100 g were quantitatively accounted for by the K in the incorporated residue.

Second, the small but combined nutrient and amendment values of pineapple residue may be enhanced by closed container systems. Thorne (1951), in his review of pineapple residue management studies,

concluded that the amendment values of incorporated residue in the field are especially low because of the susceptibility of nutrients to leaching and the limited root distribution of pineapple in the soil profile.

To summarize the results of incubation and glasshouse studies, various plant residues with N contents less than 1.0% have been shown to immobilize N upon incorporation into the soil. Apparently, appreciable amounts of both residue N and mineral N are transformed into stable soil N fractions concurrently with residue decomposition. For residues low in N, N mineralization rates have been shown to increase following initial decomposition periods, but with no net increase in cumulative N mineralized. While these results suggest that pineapple plant residue has no value as a N fertilizer, and may even be temporarily deleterious to the available N supply, various field and container studies with pineapple residue have failed to fully substantiate these conclusions.

No apparent work has been done to determine a mineralization index for pineapple soils against which the effects of residue incorporation can be evaluated. Neither has a significant amount of work been done to assess the importance of soil applied N relative to equal amounts of foliar N on the growth and N uptake of pineapple plants. Clearly, the residue effects on soil-plant N relations need to be assessed with the interactive effects of foliar applied N in mind.

Chapter III

TEN-MONTH INCUBATION EXPERIMENT

III.A. INTRODUCTION

Soil samples were collected on Oahu and Maui in April 1978 in order to survey their net N mineralization characteristics in relation to their classification, management history, and chemical characteristics. The results of the survey were reported by Ingamells and Sanford (1979) and are presented in Appendix A. From the survey, four soils were selected which had a range of mineralization index values but nearly equal total N contents (Table 1). The four soils were from the South Wahiawa Plateau and represented four series of the soil taxonomy which are most commonly associated with pineapple cultivation in Hawaii.

Subsequent to the survey, the same four soils were sampled in February 1979 to obtain surface soil (0 to 15 cm) for the glasshouse experiments reported in Chapters IV and V. Subsamples were taken for the present incubation study, the objectives being:

1. To quantitatively compare the simultaneous N mineralization over successive incubation periods for samples collected in consecutive years from four sites.

2. To derive one or more mineralization indexes which can be tested against the growth of pineapple in the glasshouse.

3. To quantitatively describe the residue effects on N mineralization.

Table 1

General information for the soils selected from Oahu.
Details can be found in Appendix A.

Soil Classification, General Location	Approximate Altitude (meters)	Mineralization Indexes		Base Status				Organic Matter		
		$^{o}N_{196}$	b		1N NH_4OAc Extractable (meq/100g)		Base Sat.	O.C.	T.N.	
		(ppm)	(ppm/day)	pH	Ca	K	(%)	(%)	(%)	C/N
Humoxic tropohumult										
Leilehua silty clay, Upper Waipio	300	60	0.30	4.0	0.1	0.08	8	2.39	0.23	10.3
Typic torrox										
Molokai silty clay loam, Lower Kipapa	150	82	0.39	4.6	4.1	0.41	70	1.67	0.21	8.0
Tropeptic eutrustox										
Lahaina silty clay, Mililani	150	85	0.39	5.2	5.4	0.57	69	1.61	0.23	6.9
Wahiawa silty clay, Upper Kipapa	200	109	0.48	4.2	0.2	0.39	18	1.64	0.21	7.7

III.B. MATERIALS AND METHODS

The general information for the four soils is given in Table 1. The incubation study included two samples of each soil. One sample represented the soil that was collected in April 1978; the other represented the soil that was collected in February 1979. The samples were air dried to moisture contents which would allow easy handling and screening. Samples collected in 1978 were sieved (1.5 mm) and stored at 10°C in plastic bags. Samples collected in 1979 were sieved (3.0 mm) and were prepared simultaneously for incubation with the stored 1978 samples. A coarser sieve was used at the second sampling to allow a more uniform packing of the soil in the incubation vials. The incubation was carried out from February 1979 until November 1979.

III.B.1. Incubation

Four 20.0 g dry weight equivalent portions of each sample were weighed into 100-cc graduated plastic cups and 200 mg of dry pineapple plant residue (leaves and stump) containing 1.0% N and ground to pass a 2-mm sieve were added to two of the four cups. Washed horticultural grade perlite, previously screened to recover only the 1- to 3-mm fraction, was added to each cup to achieve roughly 60 cc loose volume of soil and perlite. The soil-perlite or soil-residue-perlite preparations were mixed thoroughly by hand shaking. Each preparation was then carefully packed without direct pressure into a 55-cc plastic incubation vial (Figure 1). The base of the incubation vials was previously tapered by heating and a 3- to 4-mm diameter opening made which in turn was plugged with a small amount of glass wool followed

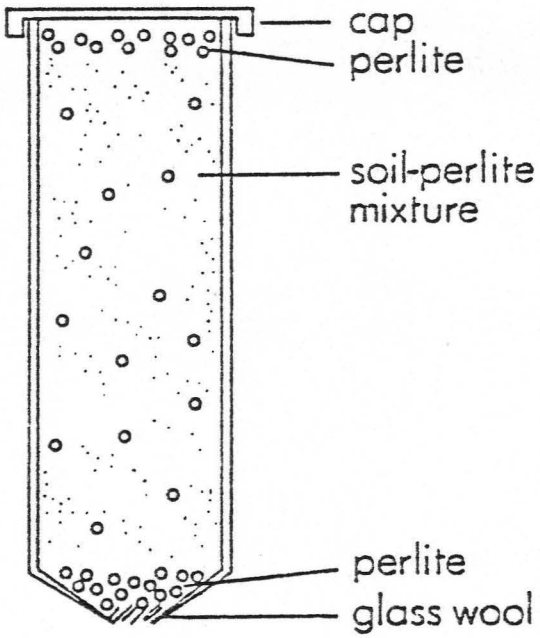

Figure 1. Prepared incubation vial.

by a small amount of perlite. After packing, the remaining volume in the top of each vial was filled with perlite. Distilled water was added to each vial to bring the moisture content of the soil to 40%. The vials were then capped and placed in plastic bags (4 vials per 1-liter bag) to prevent moisture loss during incubation. Incubation was at 34(±1)°C, which was satisfactorily close to the reported optimum temperature (Stanford, et al., 1973).

Initial levels of NH_4-N and NO_3-N in the soil solution were determined separately from the incubated samples by shaking 10 g soil in 50 ml 0.01 M $CaCl_2$ and filtering. Ammonium (NH_4-N) was essentially zero and was not determined for the remainder of the incubation study. Little or no extractable NH_4-N was found in the same soils during the preliminary incubation study.

Nitrate (NO_3-N) was extracted by leaching from the incubated samples at 30, 60, 90, 120, 150, 180, 210, 240, 270, and 285 days. The net N mineralized at 30 days was determined by the difference between the initial NO_3-N and the leached NO_3-N at 30 days. The net N mineralized at 60, 90, . . . and 285 days was determined by summing the NO_3-N determined for all previous intervals. Leachings were made with approximately 60 to 70 cc 0.01 M $CaCl_2$ followed by a N-free nutrient solution containing 2.0 mM $CaSO_4$, 2.0 mM $MgSO_4$, 5.0 mM $Ca(H_2PO_4)_2$, and 5.0 mM KH_2PO_4 with the pH adjusted to 5.0 with K_2CO_3. The leachate was collected in 100 cc volumetric flasks, thus achieving a soil:leachate ratio of 1:5 (w:v). After leaching, the incubation vials were mounted onto 1-liter suction flasks, the tops were sealed with rubber stoppers, and excess moisture was drawn from the samples

by evacuation with an aspirator to 60 cm Hg. The samples were then reincubated at 34°C.

Where the leachates were not analyzed immediately, they were preserved with 0.1% $HgCl_2$.

III.B.2. Nitrate Determination

All nitrate (NO_3-N) determinations were made by reduction to NO_2-N with amalgamated cadmium, diazotization with sulfanilamide, and color development with N-(1-naphthyl)-ethylenediamine dihydrochloride. The procedure given by the American Public Health Association (1975) was followed closely. Fourteen glass columns of amalgamated cadmium filings were prepared for this purpose and any number of the 14 (usually no fewer than 8) were used simultaneously. Each NO_3-N determination entailed passing 100 cc of standard, blank, or unknown in 0.1 M NH_4Cl through one column. After discarding the first 50 cc, 25 cc was collected for color development. The best concentration range for the unknown was 0.02 to 0.20 ppm NO_3-N. A 0.10 ppm standard was run through every column after every 2 to 4 determinations to calibrate the columns. The columns were repacked with reamalgamated cadmium when the nitrite production efficiency dropped below 75% relative to 0.100 ppm NO_2-N and NO_3-N standards.

III.B.3. Statistics

Analyses of variance (Appendix B) were made according to a one-way classification with 8 samples and 2 replicates per sample as described by Snedecor and Cochran (1967, pp. 258-285). Samples

with and without residue were handled in separate statistical analyses. Duncan's multiple range test was employed to determine significant (P = 0.05) differences among the sample means. All statistical calculations were performed using SAS Institute, Inc. (1979) programs at the University of Hawaii Computer Center.

III.C. RESULTS AND DISCUSSION

There were three distinct features of the N mineralization during incubation which allowed both a quantitative comparison of soils and a description of the residue effects. During the initial stage, lags or bursts of N mineralization occurred in some samples without residue. It was also during this stage that N immobilization in residue treated samples was most pronounced. The second stage was characterized by a prolonged linear release of mineral N over time in all samples without residue. In residue treated samples, the second stage was characterized by enhanced N mineralization. During the third stage, from roughly 210 days on, the net N mineralized began to plateau. These general results are depicted in Figure 2 and are discussed sequentially as follows:

III.C.1. Initial 30-Day Incubation Period

For 7 of the 8 residue treated samples, the initial NO_3-N in the soil solution immediately prior to residue addition was greater than the NO_3-N leached at 30 days. This measure of immobilization at 30 days' incubation was proportional to the initial NO_3-N (Table 2).

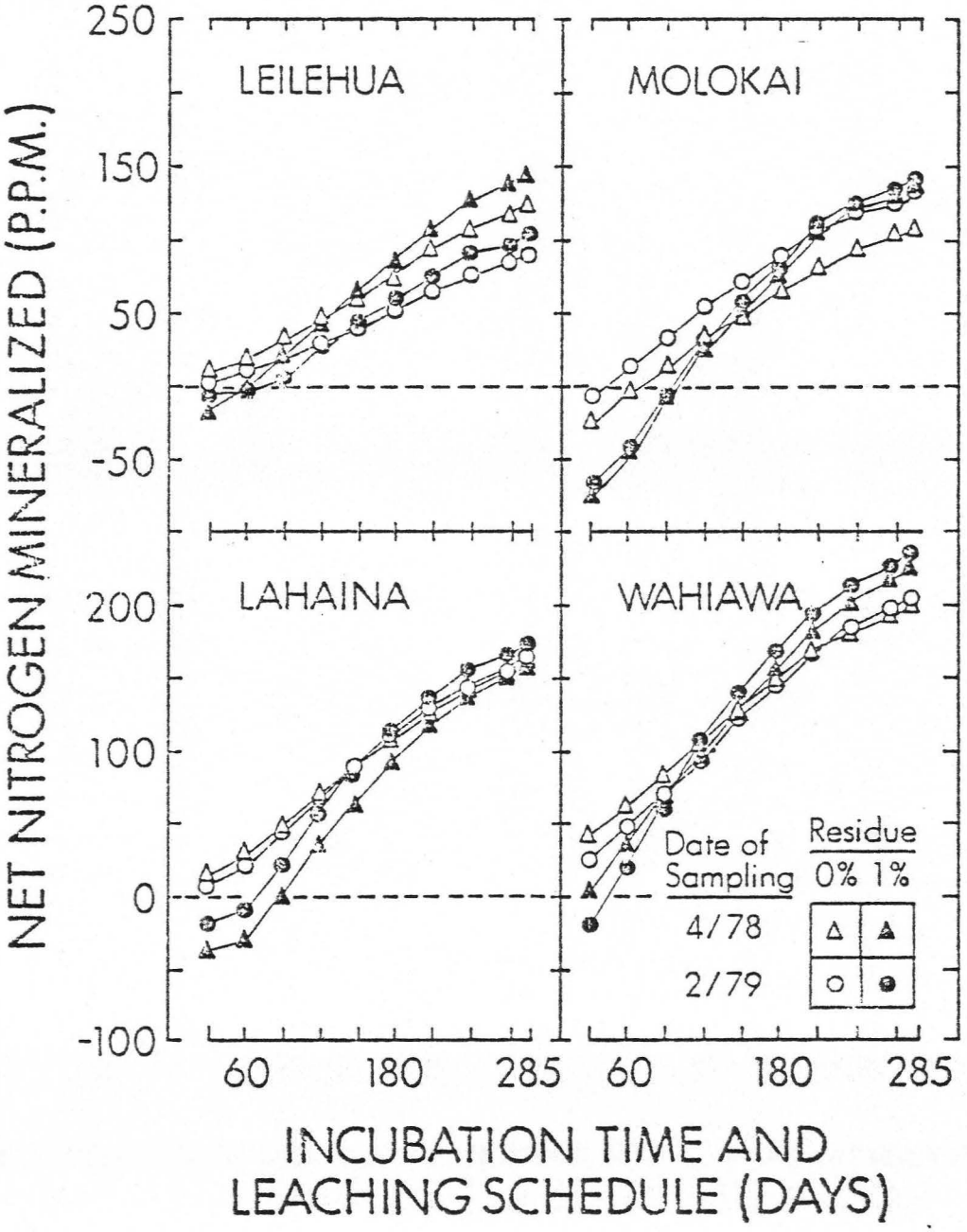

Figure 2. Net mineralization in Leilehua, Molokai, Lahaina and Wahiawa samples with and without 1.0% pineapple plant residue added immediately prior to incubation.

Table 2

Initially extractable NO_3-N and N immobilization during initial 30 days incubation in residue treated samples.

Soil	Date of Sampling	Initial NO_3-N Prior to Residue Addition (ppm)	Net N Immobilized from 0 to 30 Days in Samples with 1% Residue	
			Relative to Initial NO_3-N (ppm)	Relative to Same Samples Without Residue (ppm)
Leilehua	4/1978	19	17	22
	2/1979	9	8	9
Molokai	4/1978	386	78	49
	2/1979	77	71	61
Lahaina	4/1978	41	39	52
	2/1979	22	20	26
Wahiawa	4/1978	9	-3	39
	2/1979	90	22	48
Correlation with Initial NO_3-N (r^2)			0.56*	0.17

* denotes significance at P = 0.05

A net immobilization of N occurred in the two Molokai soils without residue during the initial 30-day incubation period (Figure 2). The quantity of N immobilized was greater in the 1978 sample where there was a greater amount of initial NO_3-N. This is in agreement with the amounts of N immobilized in the 8 residue-treated samples relative to the initial NO_3-N, the correlation with initial NO_3-N being $r^2 = 0.56$ (Table 2). In contrast, however, the immobilization effect of the residue measured relative to the same samples without residue did not correlate with the initial NO_3-N (Table 2). This latter measurement of residue-induced mobilization more correctly represents the amount of N which was a deficit to the system at 30 days incubation. These results illustrate the generalizations given by Allison (1966; 1973) that (1) N immobilization rates are proportional to the amount of mineral N (NH_4-N or NO_3-N) in the soil solution and (2) the period of time that N immobilization effects a N deficit is inversely proportional to the mineralization index.

The period of time during which N mineralization is inhibited, presumably by residue decomposition, is called here the residue-induced immobilization period. It is apparent from the curves of Figure 2 that this period varied among the samples. Extrapolating the curves indicates that for many of the samples the maximum deficit due to residue treatment actually occurred at less than 30 days incubation. The maximum deficit for the Lahaina 1978 and 1979 samples and the Leilehua 1979 sample occurred at approximately 60 days incubation.

These results demonstrated that the N deficit upon residue incorporation is determined by both (1) the immobilization of

mineral N originally present in the soil solution and (2) the residue induced immobilization period. While the second of these has been inversely related to the former and to the rate of applied fertilizer N (Waksman, 1942; Asghar and Kanehiro, 1976), the short residue induced immobilization periods for the Wahiawa 1978 and the Leilehua 1978 samples, having low initial NO_3-N levels (less than 20 ppm), are not in complete agreement with this general rule.

III.C.2. Prolonged Linear N Mineralization

For all samples without residue, the net N mineralized was linear in time from 30 days incubation to at least 210 days. After 210 days, the mineralization rates decreased with time. When the final incubation period was shortened to 15 days, mineralization rates increased over the preceding period (Figure 2), suggesting that the subsiding stage was at least partly an artifact of prolonging the incubation procedure and not entirely due to the decrease in mineralizable substrates. In the study by Ingamells and Sanford (1979) the linear N release between 16 and 196 days was not affected by the duration of the period between leachings in the range of 12 to 52 days (Appendix A).

The linear release of mineral N has not usually been reported for incubation studies. A gradual decline in the mineralization rate has usually been the result. Declining rates reported by Stanford and Smith (1972) were attributed to a progressive decrease in mineralizable substrates. Where destructive sampling techniques have been used to plot net N mineralized with time (e.g., Lathwell, et al., 1972), the reported plateauing of mineralized N may have been due to feedback inhibition.

Six of the soils used by Stanford and Smith (1972) were high enough in total N (0.19 to 0.29%) to compare with those of the present study. Their six soils released 150 to 260 ppm mineral N during 210 days incubation, quantities that are much higher than the 80, 90, 130 and 160 ppm net N mineralized during 210 days in the Leilehua, Molokai, Lahaina, and Wahiawa soils. In the present study, an attempt was made to improve the mineralization conditions over the preliminary study by providing more P and Ca in the N-free nutrient solution and reducing the soil:perlite (w:v) ratio of the incubation vial. The mineralization rates in the present study were indeed greater than those reported in Appendix A. The fact that net N mineralized was still linear over successive incubation periods, yet less than the net N mineralized in the soils studied by Stanford and Smith (1972), strongly suggests that a decreasing quantity of mineralizable substrate was not the major determinant of N mineralization. This result may be an important reflection of the intrinsic properties of the Hawaiian soils which may act, according to the suggestions of other researchers, by inhibiting microbial activity (Alexander, 1977), restricting the physical access of microorganisms to the mineralizable substrates (Allison, 1973; Campbell, 1978), or the slow chemical or biochemical conversion of organic N into readily mineralizable forms (Bremner, 1965; Keeney and Bremner, 1966a).

It is unfortunate that only a few intrinsic soil properties, such as pH (Harmsen and Kolenbrander, 1965) and allophane (Kanehiro, 1978) have been researched with regard to their inhibitory effects on N mineralization. Rate-limiting processes in the mineralization of

organic substrates by microorganisms are virtually unidentified. In the present study it is not known whether quartz sand rather than perlite, or higher soil moisture contents (e.g., 20 cm Hg rather than 60) would have resulted in a more typical curvilinear release of mineral N rather than the observed linear release.

An important aspect of the prolonged linear N mineralization is that the comparison of the four soils was precise relative to the variability which is expected to have existed in the field. Thus, the simultaneous incubation of the four soils sampled on two different occasions revealed differences between samples which were not attributable to the incubation procedure (Table 3). The linear rate was a better mineralization index than the net N mineralized because it excluded the lag or burst of N mineralization which characterized the initial stage for some samples. Lags in N mineralization during the initial 30-day incubation period are evident in Figure 2 for 5 of the 8 untreated samples. A burst of N mineralization occurred in one untreated sample (Wahiawa, 1978). Stanford and Smith (1972) also observed lags and bursts during an initial 2-week incubation period.

The mean N mineralization rates, determined by the slope of the best linear fit from 30 to 210 days, differed significantly among the 8 samples without residue, as well as among the 8 samples with 1.0% residue (Table 3). The mean N mineralization rate for samples with 1.0% residue ranged from 1.3 to 1.7 times the rates for the same samples without residue. It should be noted that this measure of residue enhanced N mineralization is a convenient one which does

not reflect the maximum residue enhancement. Where residue treatment resulted in immobilization periods of 60 days, the mean rates in Table 3 underestimate the residue-enhanced rates depicted in Figure 2.

Table 3

Mean net N mineralization rates over six successive incubation periods from 30 to 210 days.

Soil	Date of Sampling	Without Residue (ppm/day)	With 1.0% Residue (ppm/day)	Increase (%)
Leilehua	4/1978	0.48e	0.68d	43
	2/1979	0.35f	0.45e	31
Molokai	4/1978	0.60d	0.99b	65
	2/1979	0.62cd	0.99b	59
Lahaina	4/1978	0.62cd	0.87c	39
	2/1979	0.68bc	0.87c	28
Wahiawa	4/1978	0.70b	1.01b	43
	2/1979	0.79a	1.21a	53

Values for the same residue treatment followed by the same letter are not significantly different at P = 0.05.

III.C.3. Net N Mineralized from 0 to 285 Days

The net N mineralized at 285 days (Table 4) differed significantly among the 8 samples without residue as well as among the 8 samples with 1.0% residue. The net N mineralized during 285 days in samples with 1.0% residue ranged from 1.0 to 1.2 times the net N mineralized in the same samples without residue. Thus, the cumulative effect of the residue was very small.

Within each residue treatment, the greatest differences occurred among different soils, while smaller, but not necessarily insignificant, differences occurred between samples for the same soil. The net N mineralized averaged 5, 6, 7 and 10% of the total soil N in the Leilehua, Molokai, Lahaina and Wahiawa soils, respectively (Table 4). Thus, a small fraction of the soil N accounted for a large amount of the N that, in turn, may represent varying amounts of available N in different field soils.

None of the observed properties individually help explain the fact that the greatest amount of N was mineralized in the Wahiawa soil, whose base status was only slightly higher than the Leilehua soil (Table 1). On the other hand, the relatively high C/N ratio and low base status of the Leilehua soil may have been related to its low mineralization index values.

Table 4

Net N mineralized from 0 to 285 days incubation.

Soil	Date of Sampling	Without Residue (ppm)[1]	Without Residue (%)[2]	1.0% Residue (ppm)[1]	Increase Due to Residue (%)
Leilehua	4/1978	123c	5	143cd	16
	2/1979	88e	4	102e	16
Molokai	4/1978	106d	5	136d	29
	2/1979	130c	7	140cd	8
Lahaina	4/1978	160b	7	157bc	-1
	2/1979	164b	7	173b	6
Wahiawa	4/1978	199a	10	228a	14
	2/1979	206a	10	237a	15

[1] Values for the same residue treatment followed by the same letter are not significantly different at P = 0.05.

[2] % = Percent of total soil N = (net N mineralized/total N) x (100)

Chapter IV

FOUR-MONTH GLASSHOUSE EXPERIMENT

IV.A. INTRODUCTION

Much is known about the assimilation of N from the soil by pineapple and the effects of ammonium and nitrate fertilizers on various organic constituents of the plant and on plant growth (Sideris, et al., 1938; 1939). This information has been used to help explain the effects of radiation, temperature, and K and Fe fertilizers on the N nutrition of pineapple grown in the field (Nightingale, 1942). The effects of soil sterilization and fumigation on N nutrition have been studied under glasshouse conditions by carefully monitoring the N status of the soil and the plant (Tam and Clark, 1943; Tam, 1945). However, in all of the work just cited, the importance of mineralized N was secondary to the high rates of fertilizer N applied to the soil. Apparently, the only studies conducted to specifically compare N mineralization in different Hawaiian pineapple soils were the incubation of four soils by Fukunaga and Dean (1939) and the lysimeter comparison of three soils by Magistad (1932). Pineapple was not grown in either study and so the importance of mineralizable N to pineapple nutrition was not identified.

In the present study pineapple was grown in the glasshouse in order to evaluate the following:

1. The two laboratory-derived mineralization indexes reported in Chapter III (i.e., the linear mineralization rate and the net N mineralized); and

2. Pineapple response to applied foliar N and applied soil N when grown in the four soils with and without residue incorporation.

IV.B. MATERIALS AND METHODS

The following experiment was planted in the glasshouse in March 1979 and harvested in June 1979 at the Manoa branch field station of the Agronomy and Soil Science Department, University of Hawaii, Honolulu.

IV.B.1. Installation

Soil collected in February 1979 from the four sites (Table 1) was partially air dried where necessary to facilitate handling. The soils were sieved (10 mm), put in doubled 120-liter capacity plastic bags at approximately 30 kg soil per bag on a dry weight basis, and fumigated with 1.0% dibromo-chloro-propene (DBCP) at 40 cc per bag. The bags were sealed and two days later the soil was rebagged in 20 kg lots on a dry weight basis, this time leaving the bags open to promote aeration prior to residue incorporation.

Dry pineapple plant residue (leaves and stump) containing 1.0% N was chopped to pass a 10-mm sieve and was thoroughly mixed with half the soil from each site at the rate of 200 g residue per 20 kg dry weight equivalents of soil. Soil without residue was weighed into 20 kg lots, bagged, and treated and untreated lots of soil were sealed and kept on the glasshouse bench for three days to allow an initial equilibration period for N mineralization. The moisture content and 1 N KCl extractable NH_4-N and NO_3-N were then determined (Table 5).

Table 5

Soil status three days after residue incorporation and immediately before weighing into containers.

	WITHOUT RESIDUE			WITH 1.0% RESIDUE		
SOIL	H_2O (%)	NH_4-N (ppm)	NO_3-N (ppm)	H_2O (%)	NH_4-N (ppm)	NO_3-N (ppm)
Leilehua	38.2	0	15	38.0	0	0
Molokai	27.7	0	105	28.8	0	0
Lahaina	25.6	0	20	26.7	0	0
Wahiawa	32.4	1	105	33.6	0	0

The experiment was installed using a complete factorial, randomized complete block design. The four factors were:

1. Soil (Leilehua; Molokai; Lahaina; Wahiawa).
2. Incorporated residue (0.0%; 1.0%).
3. Applied soil N (0 ppm = 0 mg/pot; 100 ppm = 250 mg/pot).
4. Applied foliar N (0 mg/plant; 250 mg/plant).

There were three replicates making a total of 96 experimental units.

Six-liter, cylindrical, black plastic pots with drainage holes were prepared as follows: Approximately 2 liters of gravel were placed in the bottom of each pot followed by approximately 2 liters of perlite followed by 2.5 kg soil (dry weight basis). The lower gravel and perlite layers increased the rooting volume, facilitated

aeration, and provided some protection against overwatering. Where N was applied to the soil, 2.5 cc NH_4NO_3 solution containing 250 mg N was added just below the soil surface as the soil was being weighed into the pot.

One pineapple crown (Ananus comosus, L. Merr. "Smooth Cayenne") which was rooted in water for one week was planted in each pot. Crowns were assigned to the replicates according to size, weight, color, shape, and number and length of the root initials. Three extra crowns most representative of those selected for planting in each replicate (9 crowns total) were taken to estimate the initial plant dry weight and initial plant N content.

A N-free fertilizer solution (Table 6) was applied at the rate of 250 cc per pot per application at 3, 6, 9, and 12 weeks after planting. The fertilizer solution was made fresh prior to each application and the pH was adjusted to between 5.5 and 6.0 with KOH. Visible Fe deficiency symptoms appeared at about 12 weeks after planting, particularly for the Molokai soil. This was corrected by spraying the entire experiment with a 0.1% solution of chelated Fe (10 cc Ortho Greenol Liquid Iron in 600 cc H_2O). Supplementary K as a 1% KCl solution was also applied as a foliar spray at 12 and 13 weeks.

The pots were rotated on the glasshouse benches every two weeks to minimize bench effects. A randomized array was maintained throughout the experiment. A gravimetric check on the water content of every pot was made at every rotation. Estimates of daily hand watering requirements were made during the gravimetric checks in order to keep

the pots to near water-holding capacity.

For treatments receiving foliar N, 5.0 cc of a 2.0% NH_4NO_3 solution was applied to the upper (adaxial) surface of the longest leaves and slightly younger leaves. Solution that was not retained by the leaf surfaces collected in the leaf axils and was not lost to the soil. Applications were made 8, 9, 10, 11, 12, 13, and 14 weeks after planting. The application at 14 weeks was increased to 5.7 cc to achieve 250 mg applied N per plant.

Table 6

N-free fertilizer solution applied at the rate of 250 cc per pot at 3, 6, 9, and 12 weeks after planting.

SALT	CONCENTRATION		ELEMENT				
	(mM)	(mg/l)					
KH_2PO_4	5	680	K	P			
$Ca(H_2PO_4)_2 \cdot H_2O$	5	1260		P	Ca		
$CaSO_4 \cdot 2H_2O$	2	344			Ca	S	
$MgSO_4 \cdot 7H_2O$	2	493				S	Mg
			-----(mg element/l)----				
TOTAL	14	2777	195	465	281	128	49

IV.B.2. Leaf Length and Plant Growth Index

At 14 weeks after planting, the length of the lower (abaxial) surface of the longest leaf was measured from the point of emergence from the older leaves directly below to the tip. At 16 weeks, the longest leaf was again measured. In most cases, a different (younger) leaf was measured for the same plant at 14 and 16 weeks. The plant growth index was defined as the difference in the measured lengths at 14 and 16 weeks.

IV.B.3. Harvest

The experiment was harvested 16 weeks after planting. The longest leaf on each plant was pulled immediately prior to harvest, washed in distilled water and dried at 60°C. The longest leaves were then pooled within treatments among the three replicates to provide a sufficiently large sample for N analysis.

The soil and perlite in each pot were separated from the plant roots and the gravel, and then thoroughly mixed and subsampled to determine extractable NO_3-N.

All the remaining leaves, including the older dead leaves, were stripped from the stem. As much root material was recovered as was practical and the roots were washed and shaken free of excess moisture. The fresh and dry weights of the remaining leaves and stem+root fraction were determined.

IV.B.4. Plant Analyses

Nitrogen concentrations on a dry weight basis were determined for the following plant tissues:

1. Crowns representative of the planting material in each replicate.

2. The longest leaf pulled from the plant at 16 weeks.

3. All of the leaves at 16 weeks, regardless of age or appearance, with the exception of the longest leaf. These leaves were sometimes denoted "remaining leaves" for convenience.

4. The stem+root fraction at 16 weeks.

A semi-micro Kjeldahl digestion, followed by distillation and Nesslerization was employed as follows:

Dried, ground plant material (100 mg) was weighed into 75-cc Technicon digestion tubes. Two cc of 30% H_2O_2 was added to each tube followed by 5 to 7 cc concentrated H_2SO_4. Frothing was controlled by gentle shaking by hand. A salt mixture (2 to 4 g) of 10 K_2SO_4:1 $CuSO_4$ was added to each tube, followed by a boiling chip. The samples were placed on a cold Technicon digestion block and the temperature set for 365°C. Approximately 1 hour was required for the block to heat and digestion was allowed to continue for a maximum of 1 additional hour at 365°C. The digestates were diluted to 50 cc and aliquots containing from 0.050 to 0.250 mg NH_4-N were distilled such that the NH_4-N was collected in 100-cc volumetric flasks. Nessler reagent (3 cc per sample) was added after distillation while making the distillates up to volume (100 cc) with distilled water. Along with each set of distillates, standard solutions containing 0.050 to 0.250 mg N/100 cc as NH_4Cl were prepared in 100 cc volumetric flasks with 3 cc Nessler reagent each. Optical densities were measured between 3 and 24 hours later at 435 nm with a 1.0-cm diameter cuvette on a Bausch and Lomb Spectronic 20.

Concentrations of K, Cl, Ca, Si, Mg, P, S, and Na in the longest leaf and in the remaining leaves were determined with an X-ray quantometer by the staff of the Agronomy and Soil Science Department at Pope Laboratory, University of Hawaii.

IV.B.5. Statistics

Statistical analyses were performed using SAS Institute, Inc. (1979) programs at the University of Hawaii Computer Center. The analysis of each variable was handled exactly alike with 96 experimental units (95 total degrees freedom) except where the variable was unreplicated, in which case there were 32 experimental units (31 total degrees freedom) and the foliar interactions were deemed "error" in lieu of the replicate interactions (Appendix C).

Duncan's multiple range test was used to determine significant ($P = 0.05$) differences among the four soils and among treatments representing significant interactions. Examinations of residue interactions were considered, *a priori*, to be of principal interest; therefore, while other interactions may have been significant, they were not necessarily discussed, depending upon their contribution to the understanding of the residue effects in different soils under different N regimes.

IV.C. RESULTS AND DISCUSSION

The effects of soil, incorporated residue, and applied N, and the residue interactions are presented below for (1) N concentrations in harvested plant fractions, (2) leaf length and plant growth index, (3) leaf moisture and macroelement concentrations, (4) dry plant

weight, (5) N distribution in the plant, and (6) apparent N recovery.

The analyses of variance are presented in Appendixes C and D. Significance was recognized at $P = 0.10$. However, in view of the popular convention of claiming significance at $P < 0.05$, the $P = 0.10$ level is noted in the text where applicable.

IV.C.1. N Concentrations in Harvested Plant Fractions

Soils with the highest levels of initial NO_3-N (i.e., Molokai and Wahiawa) had significantly higher N concentrations by an average of 0.09% in the remaining leaves (i.e., all leaves composited except the longest leaf) and by an average of 0.10% in the stem+root fraction (Table 7). While the N concentration in the longest leaf averaged 0.20% more among the Molokai and Wahiawa soils than among the Leilehua and Lahaina soils, the difference was not significant, probably owing to sampling error and/or the pooling of the longest leaves within treatments for chemical analyses.

Foliarly applied N resulted in significantly higher levels of leaf N than did applications of N to the soil (Figure 3). There were probably two reasons for this result: (1) The N applied to the soil was not entirely recovered by the plant, whereas the foliarly applied N was; (2) The N applied to the soil and assimilated in the leaves resulted in a greater dry weight response than the N assimilated foliarly. Both reasons are discussed further in Chapter VI. In connection with the second, it must be recognized that applied soil N and applied foliar N were unavoidably confounded with the time of application. It is therefore likely that the dry weight accumulation

due to applied soil N was initiated earlier whereas the N applied foliarly had less time to effect a dry weight response.

The incorporation of pineapple residue depressed N concentrations in all three plant fractions by an average of approximately 0.1% (Table 7). While significant, the effect is small and certainly no greater than the difference between the effects of applied soil N and applied foliar N. Figure 3 presents a significant residue by applied N interaction for the remaining leaves, but the interaction is not consistent with the data for the longest leaf. Because of the inconsistency, and because several of the cases shown in Figure 3 demonstrated only very small residue effects, no great importance can be attributed to the effects of residue on the N concentration in the plant fractions.

Table 7

Main effects on N concentration
in three plant fractions at 16 weeks

	Leaves		
	Longest	Remaining	Stem + Roots
	(% of dry weight)		
SOIL[1]			
Leilehua	1.43a	1.11c	0.98c
Molokai	1.65a	1.23a	1.11a
Lahaina	1.51a	1.13bc	1.01bc
Wahiawa	1.70a	1.19ab	1.08ab
INCORPORATED RESIDUE[2]			
0.0%	1.62	1.20**	1.09**
1.0%	1.52	1.13	1.00
APPLIED SOIL N[2]			
000 mg	1.44	1.07	0.98
250 mg	1.70*	1.26**	1.11**
APPLIED FOLIAR N[2]			
000 mg	1.26	0.99	0.99
250 mg	1.89**	1.35**	1.10**
	(% of dry weight)		
GRAND MEAN	1.57	1.17	1.04
	(% of grand mean)		
COEFFICIENT OF VARIATION (%)	20.1	9.3	14.4

[1] Values for soils in the same column and followed by the same letter are not significantly different at P = 0.05.

[2] * and ** denote significantly greater values at P = 0.05 and 0.01, respectively.

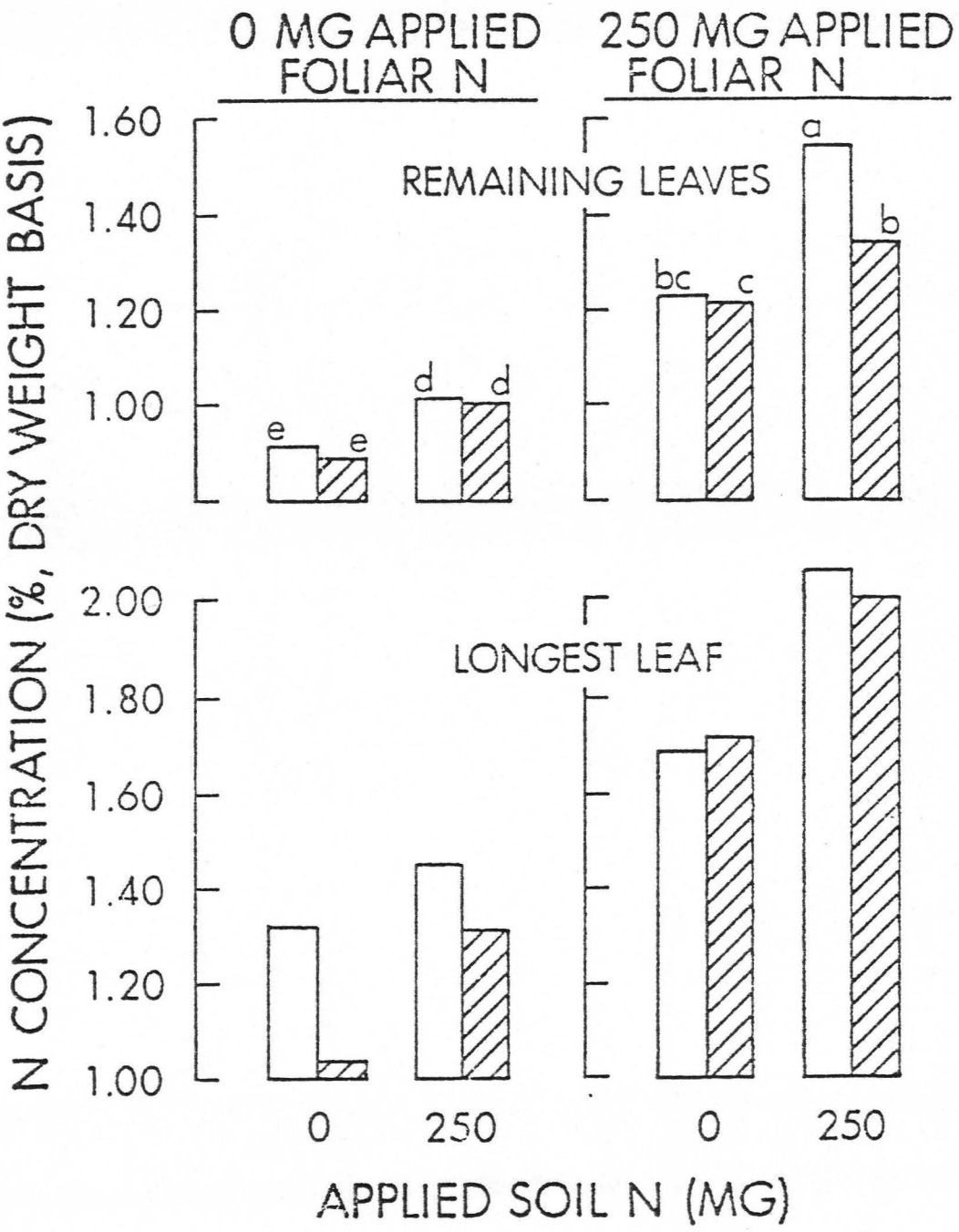

Figure 3. Nitrogen concentration in pineapple leaves at 16 weeks for the 8 residue-by-applied-N treatments. Cross-hatched bars represent treatments with 1.0% residue. Bars indicated by the same letter are not significantly different at P = 0.05.

IV.C.2. Leaf Length and Plant Growth Index

The length of the longest leaf was considered the best measurement of plant size. Only applied N significantly affected the length of the longest leaf at 14 and 16 weeks (Table 8).

The plant growth index was defined as the difference between the lengths at 14 and 16 weeks. In most cases a different (younger) leaf was measured at 16 weeks. The plant growth index was considered the best measurement of the change in size of the plant.

The plant growth index was significantly greater for the Lahaina soil that the other three soils. However, this was entirely due to the differential effect of residue in the four soils (Figure 7). These results do not correlate with available N and suggest that N was not the singlemost limiting factor during the first 16 weeks. The increased growth index for the Lahaina soil is consistent with the base status of that soil, and particularly the extractable Ca (Table 1). According to Smith (1961b), the optimum pH for pineapple root growth is generally thought to be in the neighborhood of 5.0 to 5.6.

The plant growth index among soils without residue was not significantly different (Figure 4). Because K, Ca, and Mg were abundant in the N-free fertilizer solution, the differential effect of the residue in the four soils may not have been a result of different quantities of extractable bases. It was noticed while watering to bring the soils to water-holding capacity that the residue markedly reduced the rate of evaporation from the soil. The residue effect in the Lahaina soil may have been an indirect effect

of improved soil-plant moisture relations.

Applied foliar N more greatly increased the plant growth index than did applied soil N (Figure 5). One obvious reason for this was that the N applied to the soil was not completely recovered by the plant. However, two additional factors are likely to have been involved here:

1. It has been observed that pineapple fertilized with ammonium fertilizer tends to have larger, greener, and more succulent leaves than when fertilized with NO_3-N (Sideris, et al., 1938). The reason for this has not been explained. A similar effect may have also occurred in the present experiment from the standpoint that the NH_4-N assimilated by the plant from the foliar applied NH_4NO_3 represented a larger fraction of the applied N than the NH_4-N recovered from the soil after nitrification.

2. Because the foliar N was applied during the latter half of the experiment, its effect on leaf growth may have been more pronounced during the 14- to 16-week period that the growth index was measured. The N applied to the soil prior to planting would have been taken up over a wider time interval.

Incorporated residue significantly enhanced the plant growth index only with 250 mg applied foliar N and 0 mg applied soil N (Figure 5). There is no obvious explanation for this interaction. However, it is an important indication that the residue-induced immobilization period had terminated by 14 weeks, so the plant may have benefited at this time from the NH_4-N produced by mineralization in the soil. No doubt, appreciable residue decomposition had

occurred by 14 weeks and an appreciable root system was developed to compete with nitrifying bacteria for NH_4-N. The fact that the plant growth index was not reduced by residue incorporation in any of the applied N treatments strongly implies that the residue-induced immobilization period was only temporary, as was the case in the incubation experiment (Chapter III). While incorporated residue reduced the N concentration in the plant, the fact that it did not reduce leaf length and did enhance the plant growth index is important evidence that N was not severely limiting.

Table 8

Main effects on length of longest attached leaf at 14 and 16 weeks and the growth index from 14 to 16 weeks

	Length Longest Leaf		
	14 weeks	16 weeks	Growth Index
	(cm)		
SOIL[1]			
Leilehua	28.7a	32.9a	4.2b
Molokai	28.3a	32.5a	4.2b
Lahaina	29.3a	34.0a	4.7a
Wahiawa	29.1a	33.3a	4.2b
INCORPORATED RESIDUE[2]			
0.0%	28.6	32.7	4.1
1.0%	29.1	33.6	4.6**
APPLIED SOIL N[2]			
000 mg	27.6	31.8	4.2
250 mg	30.1**	34.6**	4.5*
APPLIED FOLIAR N[2]			
000 mg	28.2	31.9	3.7
250 mg	29.5*	34.4**	4.9**
	(cm)		
GRAND MEAN	28.8	33.2	4.3
	(% of grand mean)		
COEFFICIENT OF VARIATION (%)	9.8	8.3	14.3

[1] Values for soils in the same column and followed by the same letter are not significantly different at P = 0.05.

[2] * and ** denote significantly greater values at P = 0.05 and 0.01, respectively.

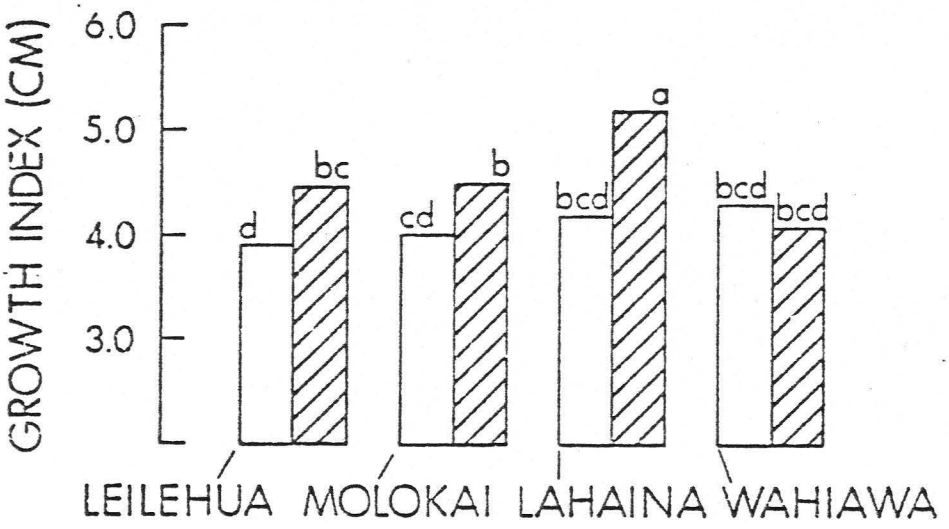

Figure 4. Growth index for the 8 soil-by-residue treatments. Cross-hatched bars represent treatments with 1.0% residue. Bars indicated by the same letter are not significantly different at P = 0.05.

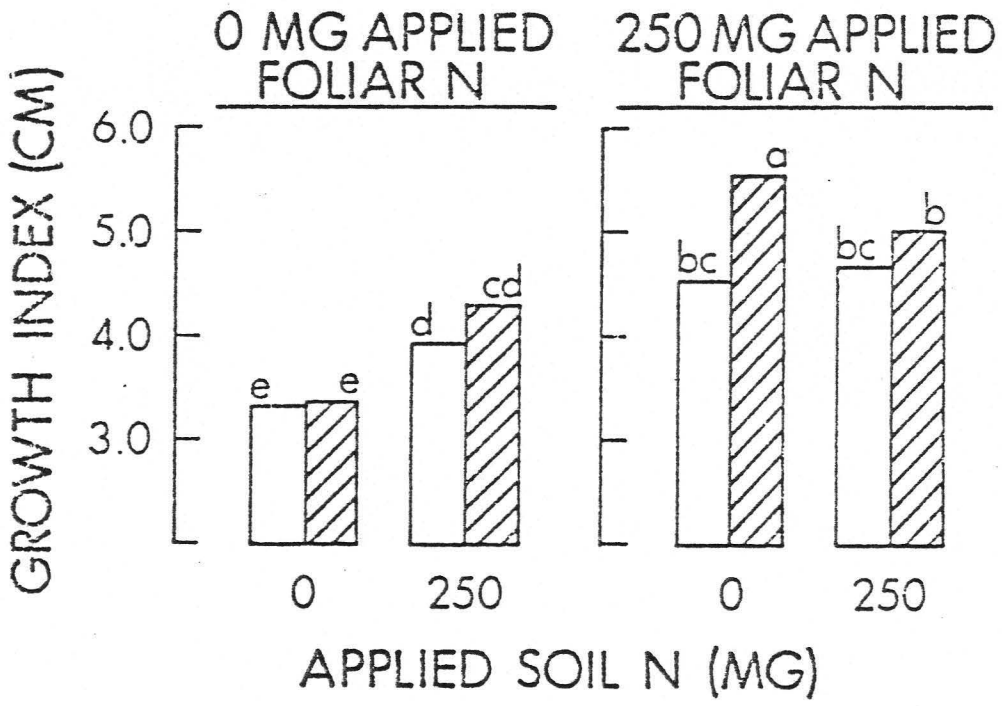

Figure 5. Growth index for the 8 residue-by-applied-N treatments. Cross-hatched bars represent treatments with 1.0% residue. Bars indicated by the same letter are not significantly different at P = 0.05.

IV.C.3. Leaf Moisture and Macroelement Concentrations

Soil had no significant effect on the percent moisture in the remaining leaves (Table 9). Significant increases in leaf moisture percentage due to incorporated residue, applied foliar N and applied soil N amounted to 1.9%, 1.0%, and 0.6%, respectively, the last of the three being significant at P = 0.10. These increases are small most probably because the samples were a composite of old and young leaves. The moisture percentage of the longest leaf was not determined.

The increased moisture content due to incorporated residue is important evidence that the soil moisture characteristics were improved by residue incorporation. Thorne (1951) and Klemmer (1961) suggested from limited available data that residue incorporation improved the physical state of the soil in terms of aeration, moisture retention, and penetrability to roots. The leaf moisture response to residue in the present study was more than just a reflection of improved growth, because the magnitude of the response relative to applied soil N and applied foliar N did not carry over to large dry leaf weight responses to residue (Table 10). This would be expected if the residue improved the physical state of the soil without providing the plant with a direct nutritional benefit.

Applications of N, either to the soil or to the leaves, also increased the moisture percentage of the leaves. Increased succulence is a well known physiological response to N fertilizers and no great importance is attached to this result except the fact that the response was not as great as the leaf moisture response to incorporated

residue (Table 9).

In order to separate the dry weight response from the nutrient recovery, the concentrations of the largely water soluble plant elements--K, Na, Ca, and Mg--were calculated on a leaf moisture basis as follows:

$$\text{concentration of element} = \frac{\text{total amount of element } (\mu g/\text{plant})}{\text{total amount of moisture } (g/\text{plant})}$$

The trend in the concentrations of K and Ca on a leaf moisture basis among the four soils was consistent with the decline in base status of the soils in a northeast direction across the South Wahiawa Plateau from where the samples were taken. Because the soils represented a transect of increased weathering across the more stable landforms of the plateau, it is not surprising that the Si concentrations (dry weight basis) in the longest leaf and the remaining leaves decreased in the order Lahaina > Molokai > Wahiawa > Leilehua (Appendixes D 1 and D 2). These results agree with the water soluble Si values reported for the same soil series by Jones and Fox (1968). The reported rainfall ranges from approximately 180 cm near the site where the Leilehua soil was collected to 75 cm near where the Lahaina soil was collected (Dole, Inc., unpublished data; Soil Conservation Service, 1976).

The available leaf and soil K, Ca, and Si data indicates that base status and/or other soil chemical properties due to weathering may have acted independently from the N regime in affecting plant growth. The relatively large plant growth index (Table 8) and dry

plant weights (Table 10) for the Lahaina soil are the best evidences of this.

Residue incorporation significantly increased the concentration of K in the leaves on a leaf moisture basis (Table 9). The increase was large enough to suggest that, in addition to the K from the N-free fertilizer solution, some quantity of K was supplied by the residue itself. The residue contained 0.7% K, so residue K could have accounted for up to 25% of the total K supply at 16 weeks. The direct contribution of residue K to the soil solution has been previously reported by Tam and Magistad (1936), and there is little doubt that residue K is the equivalent of fertilizer K where residue is incorporated into the soil.

The depressing effect of both residue and applied foliar N on Na concentration (Table 9) was probably the result of an increased moisture percentage relative to a fixed amount of Na recovered from the soil or to the antagonistic effects of other cations on Na uptake.

Incorporated residue had no effect on the Ca or Mg concentrations on a leaf moisture basis (Table 9). However, in the absence of residue, applied soil N resulted in an increase in the concentration of both elements (Figure 6). The residue by applied soil N interaction was significant at $P = 0.05$ for Ca and $P = 0.10$ for Mg. In Figure 7, the same interaction for Ca in the longest leaf is also evident, and is slightly modified from the interactions shown for K, Cl, Si, P, and S. For these five elements, but not for Ca or Mg, a significant dilution effect with the application of N to the soil occurred in the plants grown on residue-treated soils. Whereas

residue incorporation positively affected the recovery of all the macroelements except N, only applied N significantly increased the recovery of Ca from the soil. This result is in agreement with those of Ravoof (1972) who showed that in solution culture, increasing the NO_3-N supply to the pineapple roots generally enhanced Ca uptake.

Table 9

Main effects on moisture content
and K, Ca, Mg, and Na concentrations
on a moisture basis for leaves
(longest leaf excluded)

	Moisture	K	Ca	Mg	Na
	(%)	----------(µg/g H_2O)----------			
SOIL[1]					
Leilehua	85.19a	3662b	704b	650a	155a
Molokai	84.94a	3681b	714b	647a	148a
Lahaina	85.73a	4412a	814a	590a	152a
Wahiawa	84.62a	4344a	715b	653a	152a
INCORPORATED RESIDUE[2]					
0.0%	84.17	3835	737	637	164**
1.0%	86.07**	4214x	736	633	140
APPLIED SOIL N[2]					
000 mg	84.81	4029	696	627	155
250 mg	85.43x	4020	778*	643	150
APPLIED FOLIAR N[2]					
000 mg	84.62	4132	723	645	160**
250 mg	85.62*	3917	750	625	144
	(%)	----------(µg/g H_2O)----------			
GRAND MEAN	85.12	4025	737	635	152
	----------(% of grand mean)----------				
COEFFICIENT OF VARIATION	1.2	14.2	12.5	10.6	8.6

[1] Values for soils in the same column and followed by the same letter are not significantly different at P = 0.05.

[2] x, * and ** denote significantly greater values at P = 0.10, 0.05 and 0.01, respectively.

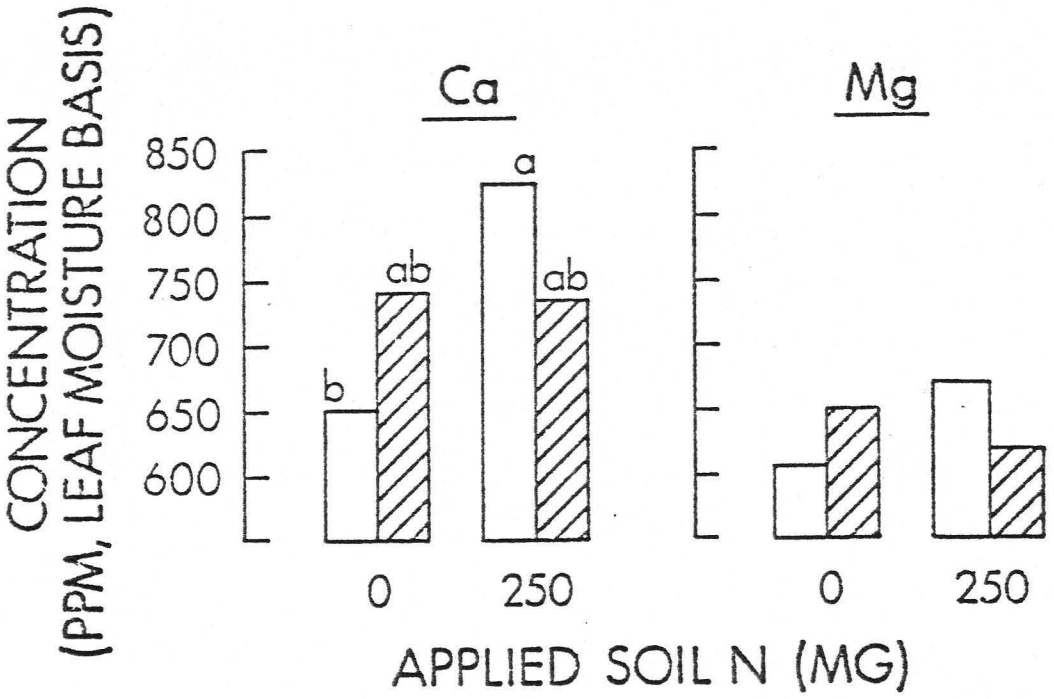

Figure 6. Concentrations of Ca and Mg on a leaf moisture basis (longest leaf excluded) for the 4 residue-by-applied-soil-N treatments. Cross-hatched bars represent treatments with 1.0% residue. Bars for Ca indicated by the same letter are not significantly different at P = 0.05. Mg concentrations were not significantly different.

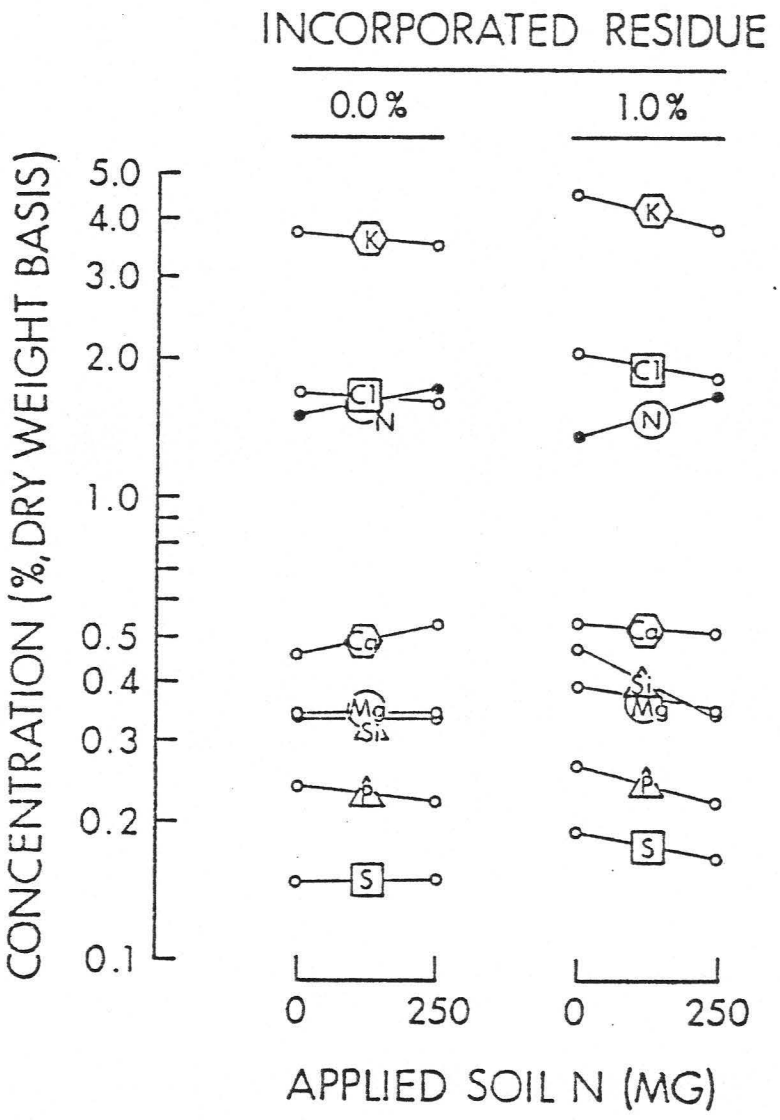

Figure 7. Effects of applied soil N with and without incorporated residue on element concentrations in the longest leaf at 16 weeks. Significant incorporated residue by applied soil N interactions are indicated by □ at P = 0.10, ⬡ at P = 0.05, and △ at P = 0.01.

IV.C.4. Dry Plant Weight

Soil had a significant effect on the dry weight of the longest leaf and the dry weight of the stem+root fraction, but the trends differed between the two fractions (Table 10). The dry weight of the longest leaf was greatest for the Lahaina soil and least for the Wahiawa soil, a result which is not consistent with the initial NO_3-N content of these soils. It is obvious that factors other than N were important. As suggested above, the relatively high base status of the Lahaina soil and enhanced soil moisture characteristics with residue incorporation may have been important. No explanation is offered for the significantly reduced dry weight of the longest leaf for the Wahiawa soil.

The dry weight of the stem+root fraction was greatest in the Leilehua soil, and least in the Molokai soil, another result which is not consistent with the initial NO_3-N in the soil. Increased root growth in the Leilehua soil was an apparent feature of the harvested plants at 16 weeks. This was very likely the result of the high aggregate stability of this soil. Increased sesquioxide content has been related to plinthization and ferralization processes (Buringh, 1970). These processes and the decreased Si content of the more highly weathered series may account for some of the structural differences observed. The aggregate characteristics were of major importance to the periodic drying of the soils during the glasshouse experiments. Aggregation in the Leilehua soil formed a surface dry mulch which markedly reduced evaporative losses. The other three soils had volumetrically higher water-holding capacities,

but surface evaporation was pronounced, particularly in the Lahaina and Molokai soils.

Among the three management factors, applied soil N had the greatest effect on dry plant weight (Table 10). Applied soil N had a greater effect than foliar N on the dry weight accumulation of the leaves (Table 10). This result is important from the standpoint that all of the N applied to the leaves was assumed to be recovered by the plant, whereas only a fraction of the N applied to the soil was expected to have been recovered by the plant. Because the application of foliar N was terminated 2 weeks before harvest, the potential dry weight response to foliar N may not have been fully observed.

Incorporated residue had a significant positive effect on the dry weight of the stem+root fraction. Again, this indicated that factors such as soil moisture had a greater effect than did the N regime on root health.

Figure 8 shows that increases in total dry weight due to residue in the presence of N were primarily due to increases in stem+root weights and not leaf weights. Applied N had no effect on the dry weight of the stem+root fraction.

Table 10

Main effects on dry plant weight

	Whole Plant	Leaves		Stem+Roots
		Longest	Remaining	
	(grams/plant)			
SOIL[1]				
Leilehua	54.8a	1.31ab	37.2a	16.3a
Molokai	52.9a	1.23bc	37.5a	13.3c
Lahaina	54.9a	1.36a	38.8a	14.7b
Wahiawa	52.0a	1.15c	36.8a	14.9b
INCORPORATED RESIDUE[2]				
0.0%	52.6	1.25	37.0	14.3
1.0%	54.7*	1.27	38.1x	15.3*
APPLIED SOIL N[2]				
000 mg	52.2	1.16	36.1	14.9
250 mg	55.0**	1.36**	39.0**	14.7
APPLIED FOLIAR N[2]				
000 mg	52.9	1.21	36.8	14.9
250 mg	54.4	1.32**	38.4*	14.7
	(grams/plant)			
GRAND MEAN	53.6	1.26	37.6	14.8
	(% of grand mean)			
COEFFICIENT OF VARIATION	8.8	13.9	9.0	14.5

[1] Values for soils in the same column and followed by the same letter are not significantly different at P = 0.05.

[2] x, * and ** denote significantly greater values at P = 0.10, 0.05 and 0.01, respectively.

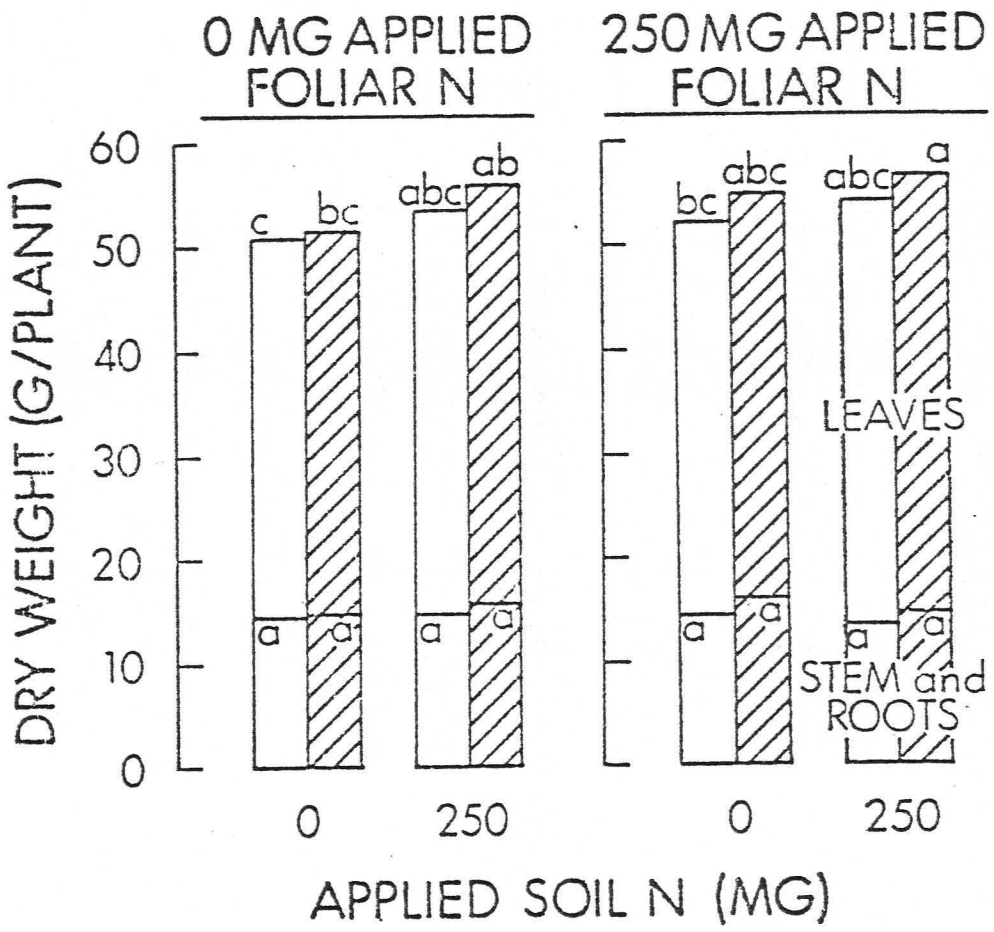

Figure 8. Total dry weight at 16 weeks broken into two plant fractions for the 8 residue-by-applied-N treatments. Cross-hatched bars represent treatments with 1.0% residue. Total dry weight values, and similarly stem+root dry weight values, indicated by the same letter are not significantly different at P = 0.05.

IV.C.5. N Distribution in the Plant

There was no significant effect of soil on the total N content of the plant at 16 weeks (Table 11). However, there were some significant trends in the N content of the remaining leaves and the stem+root fraction which more or less followed the dry weight trends. These results show very little evidence that initial NO_3-N in the soil had any effect on the N recovered by the plant at 16 weeks. Neither is there evidence that the N recovery was related to the mineralization indexes determined in Chapter III and presented in Tables 3 and 4.

Residue incorporation did not significantly reduce the N content of the plant (Table 11). However, where no N was applied, residue significantly reduced the N content of the stem+root fraction (Figure 9).

Applied N significantly increased the N content of the plant. According to the results in Table 12, of the 250 mg N that was applied to the soil, 127 mg (approximately 50%) was recovered by the plant. Again, it was assumed that 100% of the N applied to the leaves was recovered by the plant, although the increased N recovery with applied foliar N averaged only 80% of the 250 mg applied. These results are examined more carefully in Chapter VI.

For the results presented in Figure 9, there is no significant evidence that the method of N application affected the N content of the stem+root fraction. It can be seen by comparison with Figure 8 that the N content of the stem+root fraction did not follow the dry weight trend. Residue incorporation significantly reduced the N

content of the stem+roots in the absence of applied N but not in the presence of applied N. This result reflects the conclusions of Tam and Clark (1943) that there is an upper limit for the quantity of N constituents in the stem+roots, and that additional N is distributed to the leaves.

Table 11

Main effects on N distribution in the plant

	Whole Plant	Leaves		Stem+Roots
		Longest	Remaining	
	(mg/plant)			
SOIL[1]				
Leilehua	593a	19a	417b	158a
Molokai	629a	21a	464a	144b
Lahaina	609a	21a	440ab	148b
Wahiawa	620a	20a	441ab	159a
INCORPORATED RESIDUE[2]				
0.0%	621	21	447	154
1.0%	604	20	434	150
APPLIED SOIL N[2]				
000 mg	549	17	389	144
250 mg	676**	24**	492**	161**
APPLIED FOLIAR N[2]				
000 mg	526	16	364	146
250 mg	700**	25**	516**	158**
	(mg/plant)			
GRAND MEAN	613	20	440	152
	(% of grand mean)			
COEFFICIENT OF VARIATION	10.9	21.4	12.7	11.6

[1] Values for soils in the same column and followed by the same letter are not significantly different at P = 0.05.

[2] ** denotes significantly greater values at P = 0.01.

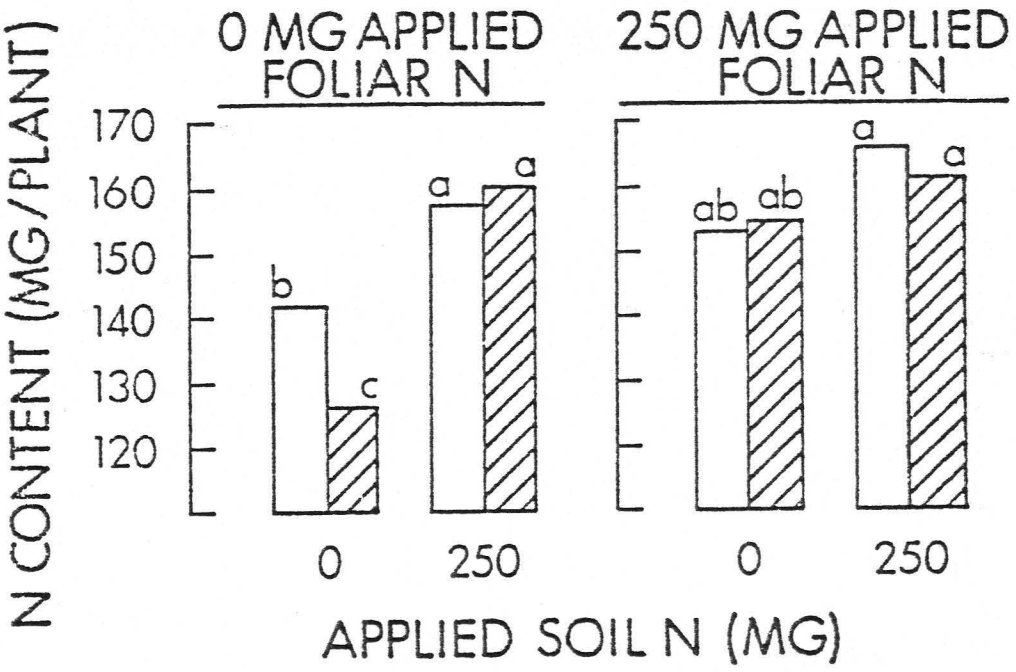

Figure 9. Total N in the stem+root fraction of pineapple at 16 weeks for the 8 residue-by-applied-N treatments. Cross-hatched bars represent treatments with 1.0% residue. Bars indicated by the same letter are not significantly different at P = 0.05.

IV.C.6. Apparent N Recovery

The total N recovered at 16 weeks (TN_{16}) was equal to the sum of the total N in the plant (PN_{16}) and the final extractable NO_3-N from the soil (SN_{16}). The apparent N recovery (%NR) was expressed as a percent of the initially accountable N (TN_0) by the equation

$$\%NR = \frac{(TN_{16})x(100)}{(TN_0)} = \frac{(PN_{16} + SN_{16})x(100)}{(PN_0 + SN_0 + AN)}$$

where PN_0 = the quantity of N in the planting material as estimated by the analysis of representative crowns, SN_0 = the quantity of N originally present in the soil solution immediately prior to the addition of residue (Table 5), and AN = the quantity of fertilizer applied to the soil and to the leaves.

The main effects of all four experimental factors were significant for both SN_{16} and %NR (Table 12). In the Molokai and Wahiawa soils, the final extractable NO_3-N (SN_{16}) was greater than in the Leilehua and Lahaina soils by an average of 100 ppm. This difference was slightly greater than the 85 to 90 ppm difference in the initially extractable NO_3-N (SN_0) for the same soils. Evidently, the additionally "available N" in the Molokai and Wahiawa soils was not recovered from the soil by the plant to any great degree. This is consistent with the insignificant differences observed for total plant N in Table 11 and N uptake in Table 12. These two values differed only by the quantity of N in the planting material (PN_0).

According to Table 12, the unrecovered N in the Molokai and Wahiawa soils averaged 12 and 10% of TN_0, respectively. The N which

was not recovered was assumed to have been immobilized or lost from the soil solution by denitrification. Immobilization, considered to be the most important, is discussed further in Chapter VI. Care was maintained throughout the experiment to prevent leaching losses from the pots.

The highly significant immobilization effect of incorporated residue is shown in Table 12. It is interesting that residue-induced immobilization did not significantly reduce the average N recovery by the plant. An average of 9% of TN_0 was unaccounted for and presumably immobilized in the residue-treated soils. While it is apparent that the residue-induced immobilization period had previously terminated in order for any amount of extractable NO_3-N to have occurred by 16 weeks, the immobilized N was not completely compensated for. Because the %NR was not significantly greater in the residue-treated soils, a latent residue-induced mineralization enhancement, as shown in the incubation experiment of Chapter III, could not be confirmed in the glasshouse.

The effects of soil and residue just discussed are illustrated in Figure 10 where TN_{16} is broken into three components. The immobilization effect of the residue in the Molokai and Wahiawa soils significantly reduced the %NR without significantly affecting the N uptake by the plant. Averaging over all N applications, SN_{16} was approximately 250 mg/pot (100 ppm) in the Molokai and Wahiawa soils without residue, 125 mg/pot (50 ppm) in the same soils with 1.0% residue, and 50 mg/pot (20 ppm) in the Leilehua and Lahaina soils regardless of residue. In contrast to the large differences in SN_{16},

the N uptake for the same treatments ranged from 232 to 272 mg/pot, a difference of only 40 mg/pot.

The net N mineralized at 16 weeks could not have been greater than zero because TN_{16} was never greater than TN_0. This, of course, assumes that denitrification in the experiment was negligible. Interpolating the data presented by Tam and Clark (1943) and Tam (1945) indicated that as much as 50 ppm N was mineralized after 10 weeks in 23-liter containers in the glasshouse. N assimilation by the pineapple from 10 weeks on in their studies allowed no further estimate of net N mineralized. However, the fact that 10 weeks elapsed prior to the rapid rates of N uptake from the soil is consistent with the evidence in the present experiment that N was not severely limiting until many weeks after planting. Because the present author used one-tenth the soil that was used in the studies of Tam and Clark (1943) and Tam (1945), it is felt that the root growth during the early weeks of the experiment inhibited net N mineralization or the conditions for mineralization in the small black plastic pots were not ideal. This is discussed further in Chapter VI. Because the apparent net N mineralized was not greater than zero, the results for this experiment do not permit an evaluation of the two laboratory-derived mineralization indexes of Chapter III.

The apparent N recovery is again illustrated in Figure 11 where residue incorporation is shown to have significantly reduced the N uptake only when N was applied both to the soil and to the leaves. Moreover, applied foliar N tended to increase the immobilization

effect of incorporated residue on SN_{16}. These two results indicate that increasing the N status of the plant with foliar N reduced the rate of N recovery by the plant from the soil.

When 250 mg (100 ppm) N was applied to the soil, 10% of TN_0, on the average, was unaccounted for at 16 weeks (Table 12). Thus, the greater the amount of mineral N in the soil at 0 weeks, the less efficient the N recovery by the plant. Again, immobilization was probably responsible for the unrecovered N.

Table 12

Main effects on N recovery measured as N uptake ($PN_{16} - PN_0$), final extractable NO_3-N (SN_{16}), and apparent percentage N recovery (%NR)

	Uptake By Plant ($PN_{16} - PN_0$)	Final Extractable (SN_{16})	Apparent Recovery (%NR)
	(mg/plant)	(mg/pot)	(%)
SOIL[1]			
Leilehua	229a	46b	100a
Molokai	265a	135a	88b
Lahaina	245a	44b	101a
Wahiawa	268a	155a	90b
INCORPORATED RESIDUE[2]			
0.0%	260	121**	98**
1.0%	243	69	91
APPLIED SOIL N[2]			
000 mg	188	67	99**
250 mg	315**	123**	90
APPLIED FOLIAR N[2]			
000 mg	165	75	96x
250 mg	339**	115**	93
	(mg/plant)	(mg/pot)	(%)
GRAND MEAN	252	95	94
	----------(% of grand mean)----------		
COEFFICIENT OF VARIATION	25.8	45.6	10.7

[1] Values for soils in the same column and followed by the same letter are not significantly different at P = 0.05.

[2] x and ** denote significantly greater value(s) at P = 0.10 and 0.01, respectively.

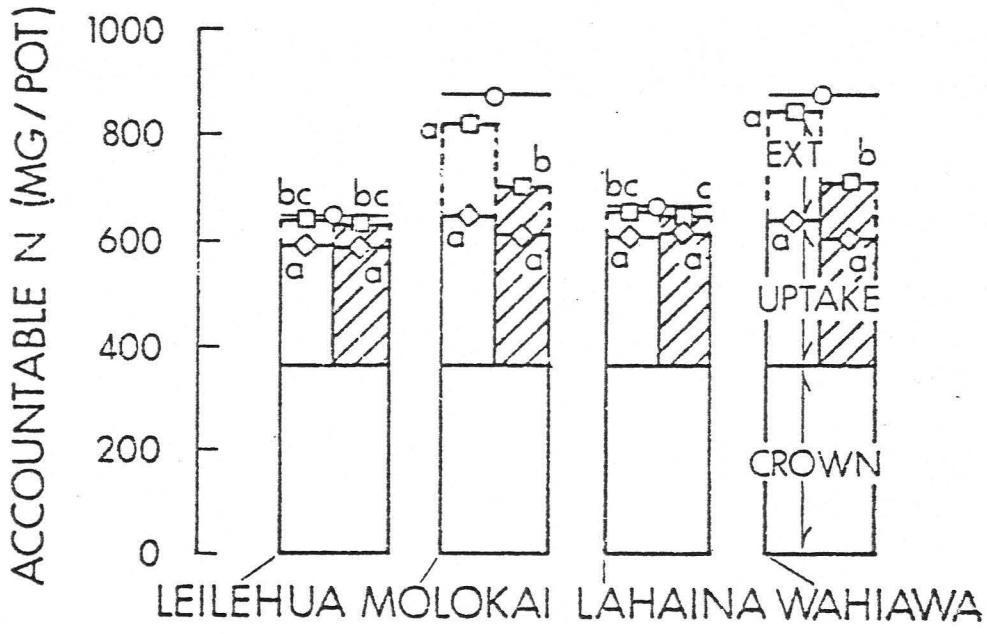

Figure 10. Final plant N (◇) and final plant N + final extractable soil N (□) at 16 weeks relative to initial N (○) for the 8 soil-by-residue treatments. The recovered N is broken in three fractions. Cross-hatched bars represent treatments with 1.0% incorporated residue. Values represented by the same symbol and indicated by the same letter are not significantly different at P = 0.05.

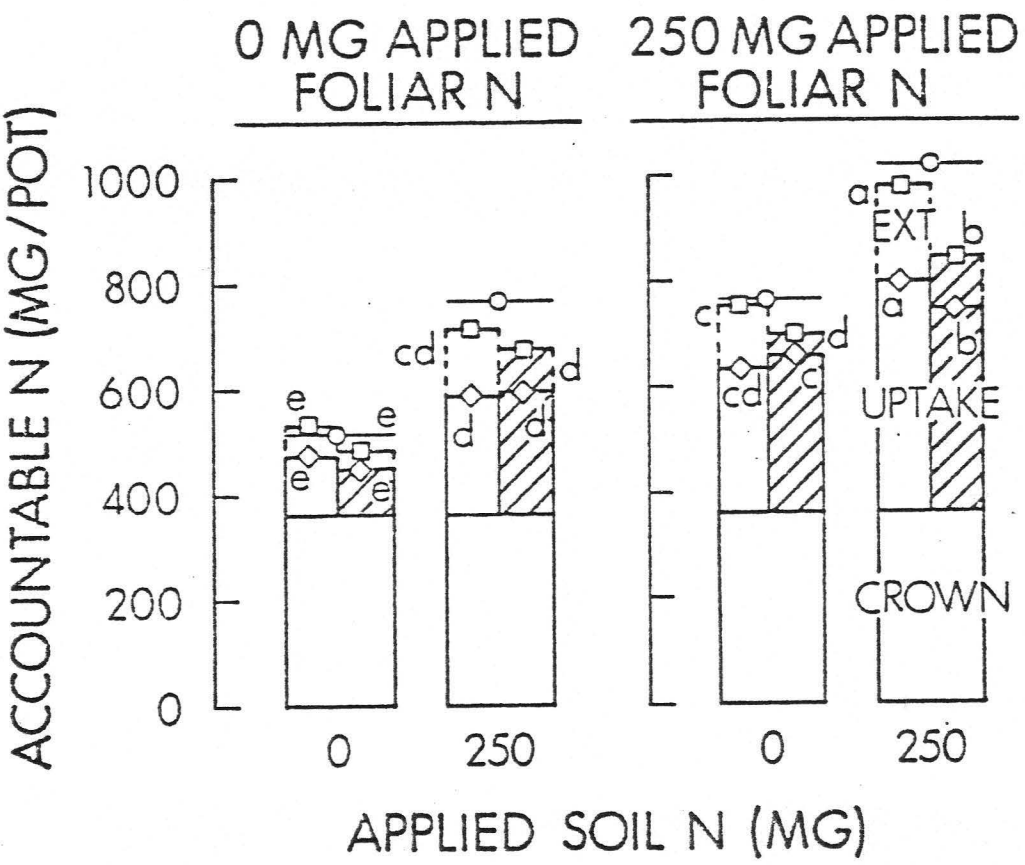

Figure 11. Final plant N (◇) and final plant N + final extractable soil N (□) at 16 weeks relative to initial N (○) for the 8 residue-by-applied-N treatments. The recovered N is broken into three fractions. Cross-hatched bars represent treatments with 1.0% incorporated residue. Values represented by the same symbol and indicated by the same letter are not significantly different at P = 0.05.

Chapter V

TEN-MONTH GLASSHOUSE EXPERIMENT

V.A. INTRODUCTION

In the four-month glasshouse experiment, factors other than N had an appreciable influence on the rooting and establishment of the plants. Apparently, no significant amount of mineralized N was recovered in addition to the N that was applied as fertilizer or was initially present in the soil solution or the planting material. Incorporated residue resulted in less available N, but at the same time enhanced plant growth. The low N demand by the plant was thought to be largely responsible for these results.

The following ten-month glasshouse experiment was installed simultaneously with the four-month experiment. While the objectives for both experiments were similar, it was particularly important in the following experiment to determine (1) whether significant quantities of mineralized N would accumulate after a sufficiently long time in soils planted to pineapple and (2) whether N mineralization in residue-treated soils would fully compensate for the N initially immobilized.

V.B. MATERIALS AND METHODS

The following glasshouse study was planted in March 1979 and was harvested in December 1979 at the Manoa branch field station of the Agronomy and Soil Science Department, University of Hawaii, Honolulu.

V.B.1. Installation

The installation and preparation were the same as for the four-month experiment except approximately 1.5 liters of gravel and 1.5 liters of perlite were layered in the bottom of the pots in order for the top of the pots to accommodate 4.0 kg soil (dry weight basis). The same experimental design was used and included the same four factors:

1. Soil (Leilehua; Molokai; Lahaina; Wahiawa).
2. Incorporated residue (0.0%; 1.0%).
3. Applied soil N (0 ppm = 0 mg/pot; 100 ppm = 400 mg/pot).
4. Applied foliar N (0 mg/plant, 400 mg/plant).

There were three replicates making a total of 96 experimental units.

The foliar N was applied weekly as described in Chapter IV. Eleven applications were made beginning 8 weeks after planting.

The pots were watered and rotated as in the four-month experiment. Four applications of the N-free fertilizer solution (Table 6) were made during the first 12 weeks after planting. During the subsequent 24 weeks, two separate, more concentrated fertilizer solutions (Tables 13 and 14) containing micronutrients were applied alternately every 3 weeks at 100 cc/pot/application until four applications of each solution were made. The solutions were prepared fresh each time. The pH of the N-, S-, and Fe-free solution (Table 13) was adjusted to between 5.5 and 6.0 with H_3PO_4.

Table 13

N-, S-, and Fe-free nutrient solution
applied four times at the rate of 100 cc per pot
during the last 26 weeks of the 38-week pineapple experiment.

SALT	mM	mg/l	ELEMENT					
KCl	34	2500	K					
K_2HPO_4	14	2500	K	P				
$CaCl_2 \cdot 2H_2O$	17	2500			Ca			
H_3BO_3	2.4	150				B		
$MnCl \cdot 4H_2O$	0.051	10					Mn	
$Na_2MoO_4 \cdot H_2O$	0.021	5						Mo
			----------(mg element/l)----------					
TOTAL	67.472	7665	2436	445	682	26.7	2.8	2.0

Table 14

N-, P-, and Ca-free nutrient solution
applied four times at the rate of 100 cc per pot
during the last 26 weeks of the 38-week pineapple experiment.

SALT	mM	mg/l	ELEMENT					
K_2SO_4	14	2500	K	S				
$MgSO_4 \cdot 7H_2O$	20	5000		S	Mg			
$FeSO_4 \cdot 7H_2O$	0.36	100		S		Fe		
$ZnSO_4 \cdot 7H_2O$	0.052	15		S			Zn	
$CuSO_4 \cdot 5H_2O$	0.040	10		S				Cu
			----------(mg element/l)----------					
TOTAL	34.452	7625	561	968	493	20.1	3.4	2.6

V.B.2. Leaf Length

At 14, 16, and 20 weeks the length of the longest leaf on each plant was measured as in the four-month experiment. The empirical relation Y = 1.117(X) + 0.467, which was derived from the four-month experiment, was used to estimate the total length of the longest leaf (Y) from the measured length of the attached leaf (X) in cm. At 28 and 36 weeks the longest leaf on each pineapple plant was pulled from the plant and then measured.

V.B.3. Harvest

The longest leaf at 28 and 36 weeks was dried, weighed and analyzed for N. At 38 weeks, the soil and perlite in each pot was separated from the plant roots and the gravel, and then thoroughly mixed and subsampled to determine 0.01 M $CaCl_2$ extractable NO_3-N. The plant was cut into two fractions:

1. Top (upper green leaves and the associated stem).
2. Bottom (lower necrotic leaves and lower stem and roots).

V.B.4. Plant Analysis

Nitrogen was determined in the plant material by the same procedure used in the four-month experiment. No other elements were examined.

V.B.5. Statistics

The same statistical procedures were used as in the four-month experiment. There was no pooling of replicates of identical treatments, hence the full 96 experimental units were included in the analyses of variance for every variable.

V.C. RESULTS AND DISCUSSION

The effects of soil, incorporated residue, and applied N, and the residue interactions are presented below for (1) N concentrations in harvested plant fractions, (2) plant size as determined by the length of the longest leaf, (3) dry plant weight, and (4) apparent N recovery.

The analyses of variance are presented in Appendixes D.3 and E.1-4. Significance was recognized at P = 0.10.

V.C.1. N Concentrations in Harvested Plant Fractions

The decrease in the N concentration in the plant from 28 to 36 weeks is evident in the results for the longest leaf (Table 15). By 36 weeks, N deficiencies were severe in all treatments. For this reason, N concentrations in the harvested plant at 38 weeks (Appendix D.3a.) were considered important only from the standpoint of determining N recovery.

Nitrogen concentrations in the longest leaf at both 28 and 36 weeks were significantly affected by soil and by applied N (Table 15). The main effect of soils on N concentration showed Wahiawa = Molokai > Leilehua > Lahaina at 26 weeks and Wahiawa = Molokai = Leilehua > Lahaina at 36 weeks. Thus, initial NO_3-N in the soil, and not mineralized N during the 38 weeks in the glasshouse, was the major determinant of N availability differences among the soils. Foliar applied N had a much greater effect on the N concentration than N applied to the soil, which was most likely due to the fractional recovery of N from the soil. These general trends were very similar to the trends observed in the four-month experiment.

At both 28 and 36 weeks, incorporated residue tended to increase the N concentration in the longest leaf for the Leilehua and Lahaina soils, had no effect in the Molokai soil, and had a negative effect in the Wahiawa soil (Figure 12). Other than these varying effects in soils, incorporated residue had no significant effects on N concentration, and hence, the initial immobilization effect of the residue did not permanently depress the N status of the plant. The trend in the N concentrations also suggests that the immobilized N resulting from residue incorporation was more quickly compensated for in the two soils with the lower levels of initial NO_3-N. The N concentrations also suggest that, in the Molokai and Wahiawa soils, the additional NO_3-N, which might be presumed to have enhanced residue decomposition, was of no benefit to the recovery of mineralized N by the plant subsequent to the residue-induced immobilization period.

Table 15

Main effects on N concentrations
in the longest leaf
at 28 and 36 weeks

	28 Weeks	36 Weeks
	(% of dry weight)	
SOIL[1]		
Leilehua	0.89b	0.65a
Molokai	0.98a	0.65a
Lahaina	0.77c	0.59b
Wahiawa	1.03a	0.69a
INCORPORATED RESIDUE[2]		
0.0%	0.92	0.63
1.0%	0.92	0.66
APPLIED SOIL N[2]		
000 mg	0.89	0.62
400 mg	0.95*	0.67**
APPLIED FOLIAR N[2]		
000 mg	0.78	0.58
400 mg	1.05**	0.71**
	(% of dry weight)	
GRAND MEAN	0.92	0.64
	(% of grand mean)	
COEFFICIENT OF VARIATION	14.1	15.3

[1] Values for soils in the same column and followed by the same letter are not significantly different at P = 0.05.

[2] * and ** denote significantly greater values at P = 0.05 and 0.01, respectively.

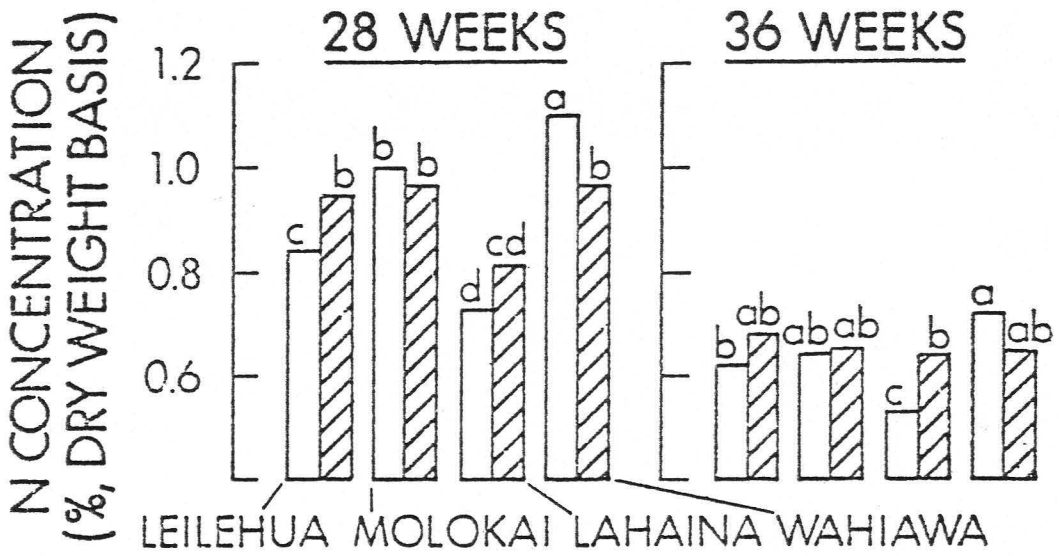

Figure 12. Nitrogen concentration in the longest leaf at 28 and 36 weeks for the 8 soil-by-residue treatments. Cross-hatched bars represent treatments with 1.0% residue. Values at 28 weeks, and similarly those at 36 weeks, indicated by the same letter are not significantly different at P = 0.05.

V.C.2. Leaf Length

The length of the longest leaf (Table 16) was significantly affected by soil and by applied soil N from 14 to 36 weeks. On the average, growth in the soils ranked Lahaina = Wahiawa > Molokai > Leilehua, however, the differences were not too great.

The main effect of applied foliar N was not significant until 16 weeks, however it must be recognized here that foliar N applications were not concurrent with soil N applications. Only 55% of the 400 mg foliar N was applied by 14 weeks, while 73% was applied by 16 weeks and 100% by 20 weeks. There was no significant effect of incorporated residue on the length of the longest leaf, nor were there any significant residue interactions for this variable.

The salient effects of both soil and applied N over time are illustrated in Figure 13. Maximum leaf growth was very similar for the four soils and occurred where both soil and foliar N were applied (—◆—). A comparison of the four soils shows that the response to applied N was low in the Wahiawa soil, moderate in the Molokai and Lahaina soils, and high in the Leilehua soil. Because of the rate of leaf elongation (depicted by the slopes of the curves in Figure 13) from 14 to 28 weeks, applied foliar N alone (—◇—) resulted in greater leaf lengths at 28 and 36 weeks than applied soil N alone (—●—). Again, the confounding of rate and time of application must be recognized in this comparison of methods of application.

Table 16

Main effects on the measurable length of the longest attached leaf at 14, 16 and 20 weeks and the length of the longest leaf pulled at 28 and 36 weeks

	Attached Leaves			Pulled Leaves	
	14 Wks	16 Wks	20 Wks	28 Wks	36 Wks
	(cm)				
SOIL[1]					
Leilehua	28.3b	32.5c	40.9c	55.5c	59.5c
Molokai	29.5ab	34.3b	44.7b	59.7b	63.1b
Lahaina	30.6a	36.3a	46.8a	62.0a	63.6ab
Wahiawa	31.1a	36.1ab	45.6ab	61.0ab	65.1a
INCORPORATED RESIDUE[2]					
0.0%	30.0	34.9	44.5	59.4	62.7
1.0%	29.7	34.7	44.5	59.8	62.9
APPLIED SOIL N[2]					
000 mg	27.6	32.1	41.7	57.6	60.1
400 mg	32.1**	37.4**	47.3**	61.5**	65.5**
APPLIED FOLIAR N[2]					
000 mg	29.7	34.2	42.5	56.4	59.2
400 mg	30.0	35.4x	46.5**	62.8**	66.4**
	(cm)				
GRAND MEAN	29.9	34.8	44.5	59.6	62.8
	(% of grand mean)				
COEFFICIENT OF VARIATION	10.4	9.0	7.2	6.0	5.3

[1] Values for soils in the same column and followed by the same letter are not significantly different at P = 0.05.

[2] x and ** denote significantly greater value(s) at P = 0.10 and 0.01, respectively.

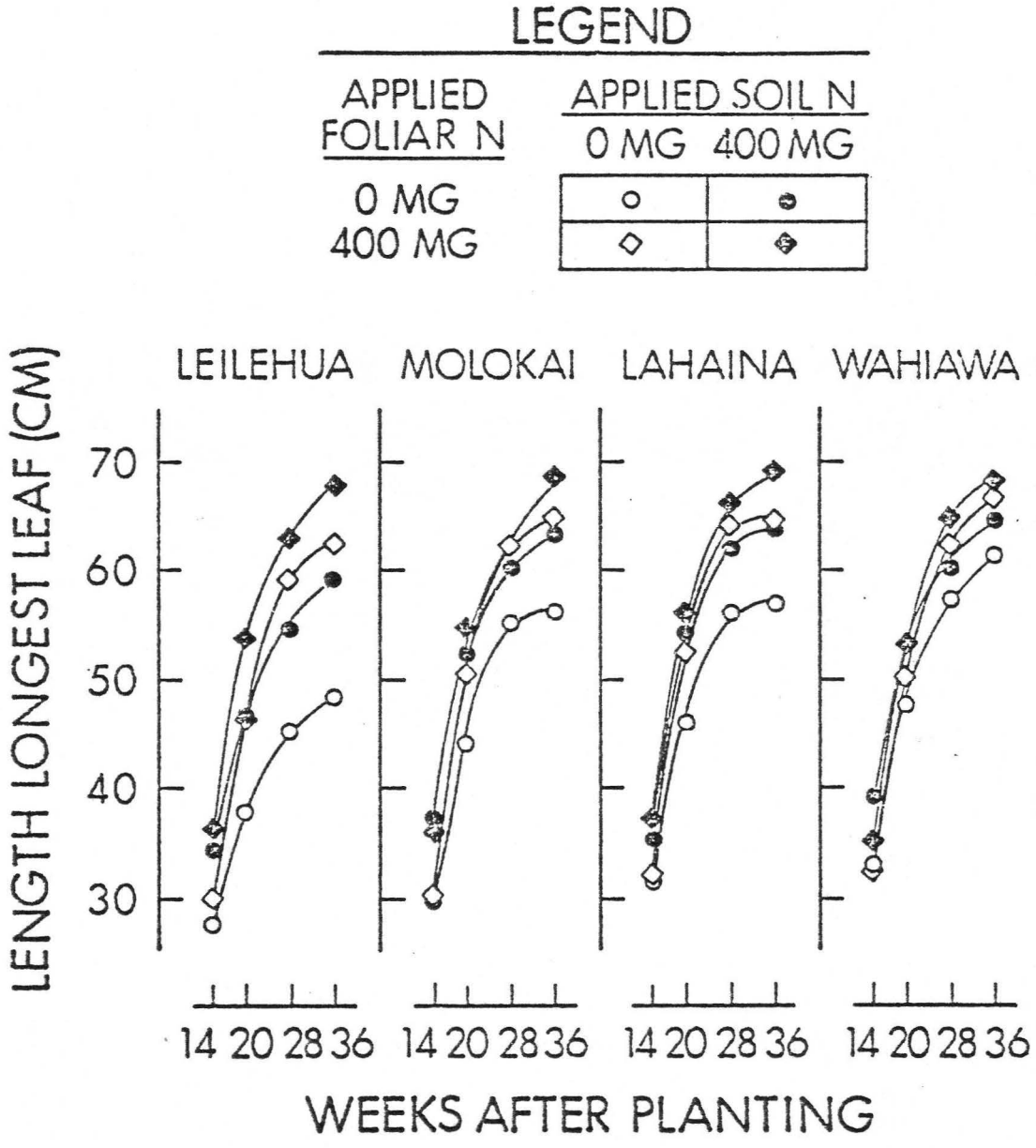

Figure 13. Pineapple growth for 16 soil-by-applied-N treatments.

V.C.3. Dry Plant Weight

The lowest dry weights for all three plant fractions occurred in the Leilehua soil (Table 17), a result which is best explained by the poor base status of this soil. While the good physical properties of the Leilehua soil provided good rooting conditions and effected plant weights at 16 weeks which were comparable to, if not greater than, the plant weights in the three other soils (Chapter IV.C.4.), these results at 38 weeks suggest that later growth was adversely affected by the soil chemical properties of the Leilehua soil.

The initial NO_3-N in the Molokai and Wahiawa soils and the relatively high base status of the Lahaina soil each resulted in improved total dry plant weights (Table 17). The initial NO_3-N in the Molokai and Wahiawa soils probably improved top growth, while the high base status of the Lahaina soil probably improved root and lower stem growth.

According to Table 17, incorporated residue tended to reduce the dry weight of all three plant fractions. However, breaking out the 16 soil-by-residue-by-applied-soil-N treatments reveals that this was not true in treatments where there was little initial NO_3-N or no applied soil N (Figure 14). This very probably demonstrates the concept explored by Pinck, et al. (1946), Nakashima (1967), Stanford, et al. (1970), Legg, et al. (1971), and others (see reviews by Bartholomew, 1965; Allison, 1966) that mineral N which is initially immobilized is not necessarily returned to the soil solution or compensated for by subsequent mineralization processes. The practical

implication here is that in order to achieve optimum levels of available N in the soil for plant growth, more fertilizer N is required when residues of low N content such as pineapple are incorporated. The higher requirement for fertilizer N can only be avoided by either foliar N applications or by applications of N to the soil after sufficient residue decomposition has occurred to minimize the immobilization of fertilizer N.

The dry weight of the bottom fraction of the plants also tended to be adversely affected by residue incorporation. Thus, root growth was enhanced by residue incorporation during the early weeks after planting, but was later depressed by the limited N reserves in the residue treatments. Even where enhanced mineralization in residue treatments might have been able to completely compensate for the earlier immobilization of N, the plant demand was probably too great too soon in relation to the slowly available N. Comparing the residue effects on root growth for the two glasshouse experiments suggests that the critical period for supplying N to the plant was near to, but not sooner than 16 weeks after planting. A similar conclusion was reached by Gowing and Klemmer (1961) in their field study.

The application of N to the leaves on the average significantly increased the total dry weight of the plant at 38 weeks from 83 g to 106 g. Application to the soil increased the dry weight to 115 g. Application to both the leaves and the soil increased the dry weight to 127 g. All four dry weight values were significantly different at $P = 0.05$. Hence, in contrast to the results for leaf

length in the preceding section, soil N was superior to foliar N when applied alone. These relative effects of N application on dry weight are illustrated in Figure 15 along with the negative effect of incorporated residue.

Also reported in Table 17 are the main effects on the dry weight ratios between the top and bottom fraction of the plant at 38 weeks. In general, the higher the initial NO_3-N in the soil the higher the ratio. Applied N was also associated with higher top:bottom ratios.

Table 17

Main effects on the total dry weight and the dry weight distribution

	Cumulative Total	Pulled Leaves	Top	Bottom	Top-Bottom Ratio
	(grams/plant)				
SOIL[1]					
Leilehua	99b	6.6c	57.8c	35.1c	1.62b
Molokai	119a	7.8b	73.3a	37.5bc	1.96a
Lahaina	118a	8.0ab	68.4b	41.7a	1.67b
Wahiawa	125a	8.3a	76.9a	39.6ab	1.98a
INCORPORATED RESIDUE[2]					
0.0%	121**	7.8*	72.5**	40.7**	1.80
1.0%	109	7.5	65.7	36.3	1.82
APPLIED SOIL N[2]					
000 mg	101	6.8	57.5	36.6	1.58
400 mg	130**	8.6**	80.7**	40.3**	2.03**
APPLIED FOLIAR N[2]					
000 mg	106	6.7	60.7	38.3	1.58
400 mg	125**	8.6**	77.4**	38.7	2.04**
	(grams/plant)				
GRAND MEAN	115	7.7	69.1	38.5	1.81
	(% of grand mean)				
COEFFICIENT OF VARIATION	9.7	10.3	12.1	14.3	16.9

[1] Values for soils in the same column and followed by the same letter are not significantly different at P = 0.05.

[2] * and ** denote significantly greater value(s) at P = 0.05 and 0,01, respectively.

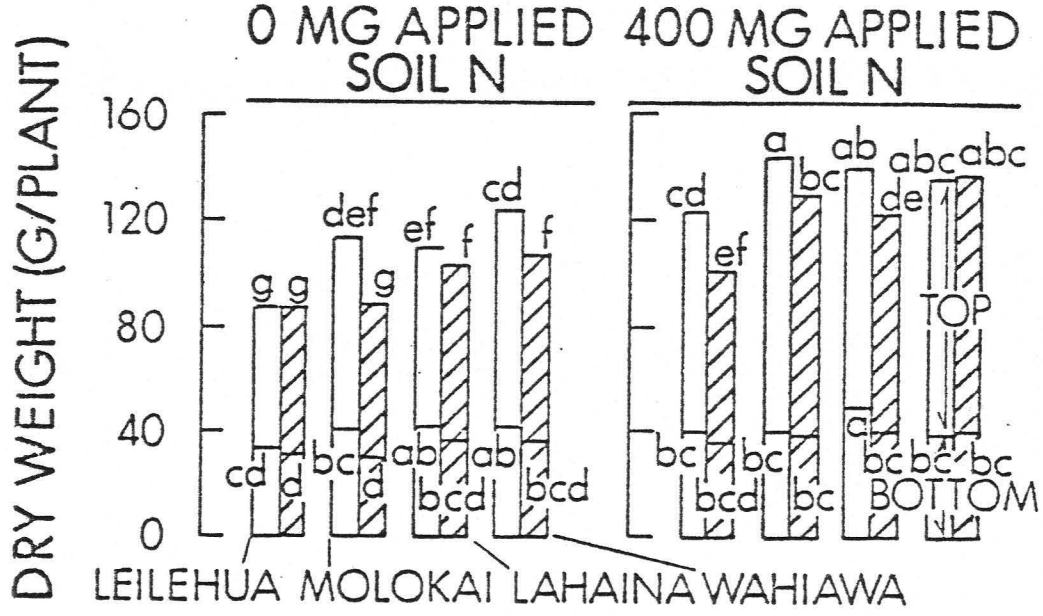

Figure 14. Total dry weight at 38 weeks broken into two plant fractions for the 16 soil-by-residue-by-applied-soil-N treatments. Cross-hatched bars represent treatments with 1.0% residue. Total dry weight values, and similarly the dry weight values for the bottom fraction, indicated by the same letter are not significantly different at P = 0.05.

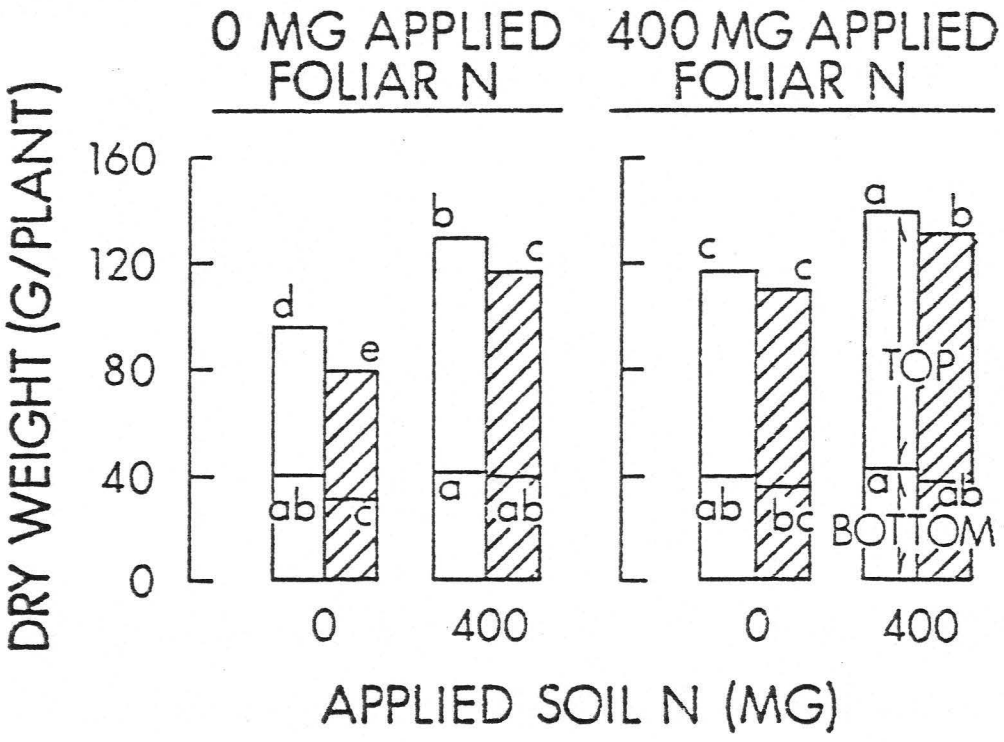

Figure 15. Total dry weight at 38 weeks broken into two plant fractions for the 8 residue-by-applied-N treatments. Cross-hatched bars represent treatments with 1.0% residue. Total dry weight values, and similarly the dry weight values for the bottom fraction, indicated by the same letter are not significantly different at P = 0.05.

V.C.4. Apparent N Recovery

The N recovered at 38 weeks was identical to the total plant N since there was virtually no extractable soil NO_3-N. Using the same expression for apparent N recovery (%NR) as in the four-month experiment,

$$\%NR = \frac{(TN_{38})x(100)}{(TN_0)} = \frac{(PN_{38})x(100)}{(PN_0 + SN_0 + AN)},$$

where $TN_{38} = PN_{38}$ = the total plant N at 38 weeks, and TN_0, PN_0, SN_0, and AN are as defined in Chapter IV.C.6.

The trend in N uptake among the four soils followed the order Wahiawa > Molokai > Lahaina > Leilehua, and the trend was reversed for %NR (Table 18). The trend in N uptake may reflect intrinsic N mineralization differences between the Wahiawa and Molokai soils and between the Lahaina and Leilehua soils since the differences are consistent with the laboratory-derived mineralization indexes. However, the initial NO_3-N was again the predominant factor. The trend in %NR followed the general rule that the greater the amounts of "available N" in the soil, the less efficiently was the N recovered by the plant.

Incorporated residue significantly reduced the N uptake in the Molokai and Wahiawa soils but not in the Leilehua and Lahaina soils (Figure 16). This soil by residue interaction for N uptake was highly significant ($P = 0.01$) and the trend among the 8 soil-by-residue treatments was similar in the four-month experiment where the same interaction was not significant. On the average, incorporated residue reduced the %NR by 5%. On the basis of %NR,

the soil-by-residue interaction was expressed as follows, where values followed by the same letter are not significantly different at P = 0.05:

	Lahaina	Leilehua	Wahiawa	Molokai
0.0% Residue	105a	96c	98c	88d
1.0% Residue	110a	101bc	86d	72e

Applied soil N reduced the %NR by an average of 9% and applied foliar N had no significant effect on the %NR (Table 18). The %NR ranged from 85% to 105% among the 8 residue-by-applied-N treatments (Figure 17) and %NR presented no significant residue by applied N interaction.

Table 18

Main effects on N recovery measured as N uptake ($PN_{38} - PN_0$) and apparent percentage N recovery (%NR)

	Uptake By Plant ($PN_{38} - PN_0$)	Apparent Recovery (%NR)
	(mg/plant)	(%)
SOIL[1]		
Leilehua	443d	99b
Molokai	609b	80d
Lahaina	501c	107a
Wahiawa	730a	92c
INCORPORATED RESIDUE[2]		
0.0%	598**	97**
1.0%	543	92
APPLIED SOIL N[2]		
000 mg	415	99**
400 mg	726**	90
APPLIED FOLIAR N[2]		
000 mg	383	96
400 mg	758**	94
	(mg/plant)	(%)
GRAND MEAN	571	95
	-------(% of grand mean)---------	
COEFFICIENT OF VARIATION	11.3	8.0

[1] Values for soils in the same column and followed by the same letter are not significantly different at P = 0.05.

[2] ** denotes significantly greater values at P = 0.01.

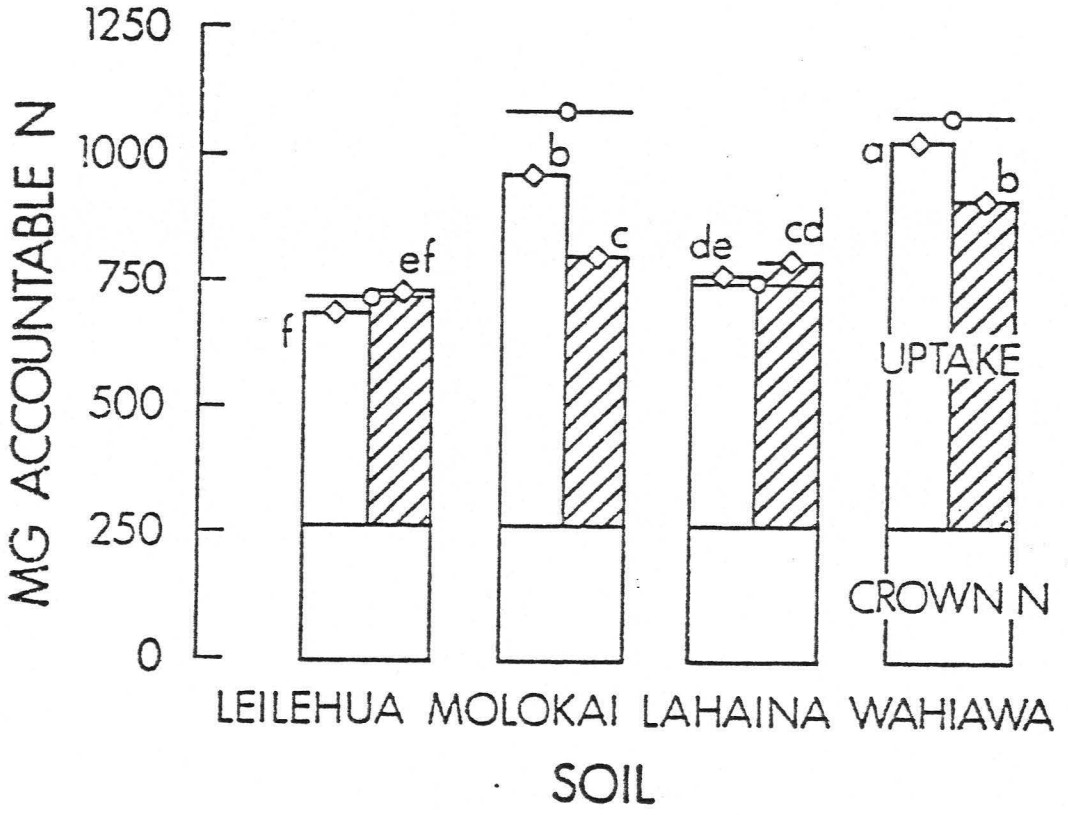

Figure 16. Final plant N (◇) relative to initial N (O) for the 8 soil-by-residue treatments. The plant N is broken into two fractions representing N uptake and initial crown N. Cross-hatched bars represent treatments with 1.0% residue. Values for total plant N indicated by the same letter are not significantly different at P = 0.05.

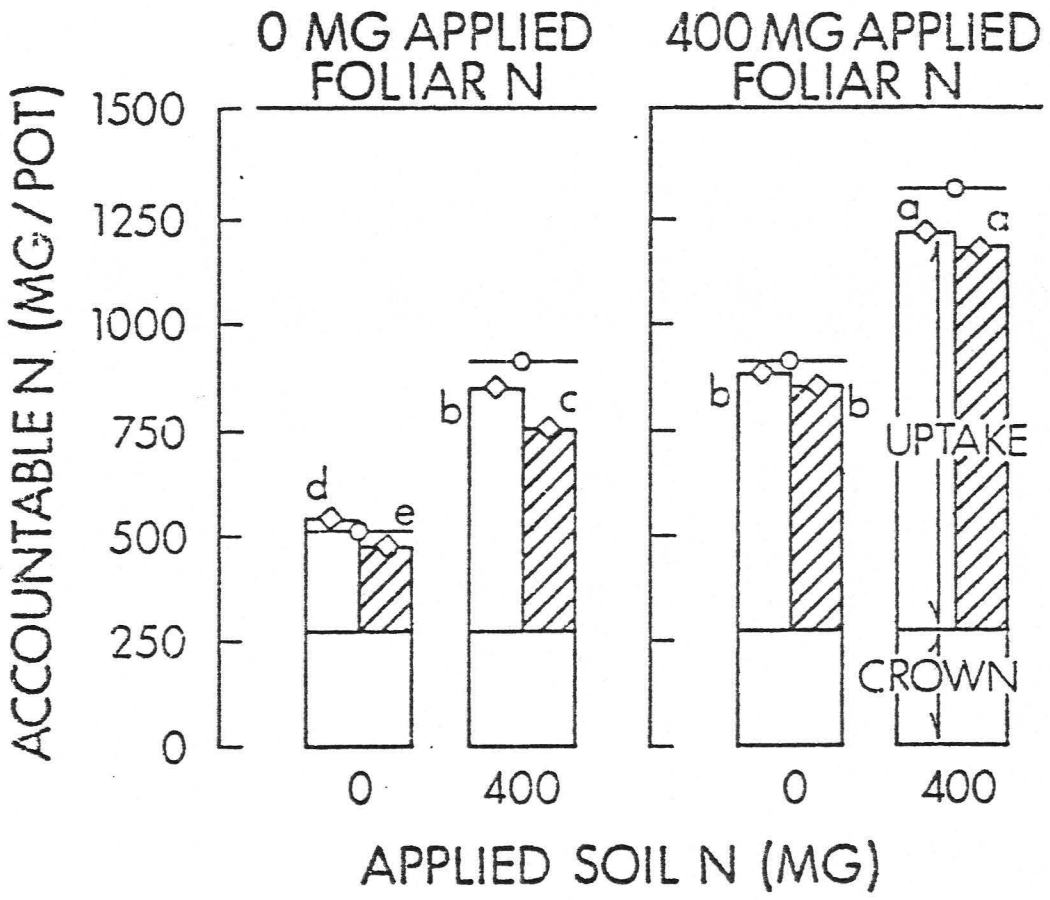

Figure 17. Final plant N (◇) relative to initial N (O) for the 8 residue-by-applied-N treatments. The plant N is broken into two fractions representing N uptake and initial crown N. Cross-hatched bars represent treatments with 1.0% residue. Values for total plant N indicated by the same letter are not significantly different at P = 0.05.

Chapter VI

DISCUSSION

VI.A. N RELATIONS IN SOILS WITHOUT RESIDUE

"Available N" denotes the supply of mineral N to the plant from three sources: (1) N initially present in the soil solution; (2) N applied as fertilizer; (3) N added to the soil solution by mineralization. In the experiments reported here, the third component was shown to be a very minor determinant of the N supply to pineapple in the glasshouse, in spite of the two-fold range in the laboratory-derived mineralization indexes for the same soils. The level of N initially present in the soil solution greatly affected N uptake by the pineapple, but had less effect on total dry weight. These general results are presented in Table 19 where the laboratory and glasshouse data for soils without residue from the individual experiments can be conveniently compared.

Laboratory-derived mineralization indexes have not always correlated well with growth and N uptake in the glasshouse (Harmsen and van Schreven, 1955; Peterson, et al., 1960; Gallagher and Bartholomew, 1964). Bremner (1965), Allison (1966; 1973), and Robinson (1975) discussed many of the factors responsible for poor correlations. Among these factors, root-induced N immobilization is suggested by the present author to have been of particular importance to the results reported here. As roots accumulate in a finite volume of soil in containers, organic secretions and

Table 19

Estimated N uptake and total dry weights of pineapple at 16 and 38 weeks in four soils without residue treatment.

Soil	Laboratory-Derived Mineralization Indexes[1]		Soil and Plant Status in Glasshouse				
	Linear Min. Rate[2]	Net N Mineralized[3]	Initial[4] NO_3-N	Estimated N Uptake[1]		Total Dry Weight[1]	
				16 weeks	38 weeks	16 weeks	38 weeks
	(ppm/day)	(ppm)		(mg/plant)		(g/plant)	
Leilehua	0.35c	88c	15	229a	434d	54.6a	103b
Molokai	0.62b	130d	105	285a	688b	51.8a	129a
Lahaina	0.68b	164b	20	244a	483c	52.3a	124a
Wahiawa	0.79a	206a	105	283a	787a	51.6a	129a
	Correlations with:			(r^2)			
	Linear Min. Rate (laboratory)			0.52	0.55	0.88	0.85
	Net N Mineralized (laboratory)			0.35	0.48	0.66	0.60
	Initial NO_3-N (glasshouse)			0.97*	0.94*	0.57	0.56

[1] Values in the same column followed by the same letter are not significantly different at P = 0.05.

[2] Linear mineralization rates are from Table 3.

[3] Net N mineralized is from Table 4.

[4] Initially extractable NO_3-N at the installation of the glasshouse experiments (Table 5).

[5] * denotes significance at P = 0.05.

sloughed root tissue act to widen the C:N ratio of localized microbial environments. The competition for N between the plant and the microorganisms is thus intensified and less N is removed from the soil by the plant. Unfortunately, there appears to be no reliable data on the amount of organic matter excreted by plant roots in soil and on the C:N ratio of the excretions. Clark (1949), Legg and Allison (1961), and Harmsen and Jager (1962) presented some evidence that a root-induced N immobilization artifact may be real in many glasshouse situations where small containers are used. It is important to note that in the present experiments, the volume of soil per plant was less than one-tenth that of a 15-cm hectare plow layer at 40,000 plants/ha.

Anticipating the possibility of root-induced N immobilization, the present author prepared fallow soils simultaneously and in like manner with the soils planted to pineapple. A comparison of the apparent net N mineralized at 16 and 38 weeks was made between the fallow and the cropped soils (Table 20). The apparent N mineralized was consistently greater in the fallow soils than in the cropped soils. This result is in agreement with the results of Goring and Clark (1948), who reported that N mineralization was reduced to zero after 5 weeks in pots cropped with tomato and tobacco seedlings, while mineralization continued in a linear fashion until 13 weeks in fallow pots. In another study, Englerth (1969) reported N uptake values which showed no evidence of N mineralization when pineapple was grown for 6 months in 5-gallon containers.

Table 20

Apparent N mineralized in the glasshouse for fallow and cropped soils and its correlation with the laboratory-derived mineralization indexes. Data are for soils without residue treatment and without applied soil N.

	38 Weeks; 4.0 Kg Soil					
		Planted			Planted	
Soil	Fallow[1]	000 mg foliar N	250 mg foliar N	Fallow[1]	000 mg foliar N	400 mg foliar N
	(ppm)					
Leilehua	17.5	6.3	-1.8	19.9	-5.0	-4.2
Molokai	12.0	9.8	-16.2	23.4	-20.7	-18.5
Lahaina	23.6	21.6	5.4	40.7	23.4	9.2
Wahiawa	16.1	-4.9	-5.1	48.4	16.0	-14.4
Correlations with:	(r^2)					
Linear Min. Rate[2]	0.00	0.02	0.00	0.75	0.25	0.02
Net N Mineralized[3]	0.03	0.08	0.02	0.92*	0.43	0.00

[1] The main effects of soil, incorporated residue, and applied soil N and the analyses of variance for these factors and their interactions are presented in Appendix F.

[2] Linear mineralization rates are from Table 3.

[3] Net N mineralized is from Table 4.

[4] * denotes significance at P = 0.05.

It is suggested here that the conditions for mineralization in the black plastic pots in the glasshouse were more adverse than field conditions as a result of (1) the increased magnitude of the temperature fluctuations, (2) the increased frequency of the moisture fluctuations, and (3) the modification of soil structure in the containerized regime. The apparent N mineralized (Table 20) was indeed very small and was still smaller with either incorporated residue or applied soil N (Tables 12 and 18 and Appendix F). The actual net N mineralized may have exceeded the apparent values depending upon the amount of N lost by denitrification or by processes other than N immobilization. Denitrification and other avenues of N loss from pots have been attributed to low recovery rates of mineral N (Allison, 1966). Losses of N other than by N immobilization were of unlikely importance to the results reported in the present study in view of the following:

There is apparently no evidence that denitrification is of practical significance in aerated oxisols and ultisols of the Wahiawa plateau. In fact, Balasubramanian and Kanehiro (1976) concluded that a Molokai (torrox) and a Paaloa (tropohumult) soil only poorly sustained denitrification under anaerobic conditions. In another study by Asghar and Kanehiro (1976) denitrification did not occur in a Molokai soil at 60% of the moisture holding capacity and at redox potentials as low as 400 mv. In the present study, anaerobic conditions were minimized by the rapid rates of moisture loss during the day. However, the effect of moist conditions during

the night where watering was done late in the day was of possible significance.

The small amounts of apparent N mineralized in the glasshouse have little bearing on the application of laboratory-derived mineralization indexes toward field research. The high correlations between the two laboratory-derived indexes and the apparent N mineralized in fallow soils at 38 weeks (r^2 = 0.75 and 0.92; Table 20) may be an honest reflection of the importance of intrinsic mineralization differences. These two correlations for fallow soils at 38 weeks stand in sharp contrast to all other correlations for cropped soils and the correlations for fallow soils at 16 weeks. According to Allison (1966; 1973) both NH_4-N and NO_3-N operate by mass action to increase N immobilization rates. Thus, high NO_3-N levels may explain the lower amounts of apparent N mineralized for the fallow Molokai and Wahiawa soils at 16 weeks. Remembering that mineralization probably proceeded under adverse conditions, the high correlations at 38 weeks for fallow soils (Table 20) suggest that intrinsic mineralization differences were slowly manifested, but only (1) after equilibration with initially high levels of NO_3-N and (2) in the absence of root confinement. Both the effects of NO_3-N and root confinement are artifacts which have less of an overshadowing effect on mineralization under field conditions because both NO_3-N and plant roots are dispersed in the soil profile.

Because N immobilization was proportional to the amount of mineral N present in the soil, the apparent N recovery (%NR) was inversely related to both the initial NO_3-N in the soil and the

applied soil N. Increased concentrations of mineral N in the soil solution resulted in greater quantities of N being immobilized, even without residue treatment (Table 21). From Table 21 it can be shown that an average of 5 and 8% of the TN_0 at 16 and 38 weeks, respectively, was immobilized as a result of the 85 to 90 ppm additional initial NO_3-N in the Molokai and Wahiawa soils. Nearly equal percentages, 7 and 9%, were immobilized as a result of the application of N at 100 ppm to the soil.

Going back to Table 20, it can be concluded that applied foliar N also resulted in greater amounts of N being immobilized in the soil by either 16 or 38 weeks, depending upon the soil. The foliar applied N probably reduced the rate of N uptake from the soil; thus, the longer the mineral N remained in the soil, the greater was the amount of N immobilized, presumably because of the localized effects of root confinement within the pots. As a check on the N volatilized after foliar application, the plant recovery of fertilizer N applied simultaneously to the leaves of plants grown in an N-void vermiculite-perlite medium was not significantly different from 100%.

According to Allison (1966) the usual range of fertilizer N recovery in glasshouse experiments is 50 to 100%. In the present study, it was estimated that the additionally available NO_3-N (85 to 90 ppm calculated by difference) in the Molokai and Wahiawa soils was recovered by the plant at the average rate of 24% at 16 weeks and 75% at 38 weeks. The uptake of N from the soil by pineapple was probably slow during the initial stages of rooting and plant establishment, thus allowing a greater percentage of the N in the soil

Table 21

Effect of applied soil N in each of four soils without residue on apparent N recovery at 16 and 38 weeks.

Soil	"Available Soil N" Not Accounting For N Mineralization			Apparent N Recovery	
	Initial	Applied	Total	16 weeks	38 weeks
	----------(ppm)--------			-----(% of TN_0)----	
Leilehua	15	000	15	102	96
		100	115	97	96
Molokai	105	000	105	100	91
		100	205	90	86
Lahaina	20	000	20	108	117
		100	120	94	94
Wahiawa	105	000	105	98	102
		100	205	97	94

IMMOBILIZATION ATTRIBUTED TO THE ADDITIONAL NO_3-N IN THE MOLOKAI AND WAHIAWA SOILS:

000 ppm applied soil N	6	10
100 ppm applied soil N	2	5

IMMOBILIZATION ATTRIBUTED TO 100 PPM APPLIED SOIL N:

in the Leilehua and Lahaina soila	8	12
in the Molokai and Wahiawa soils	6	6

solution to be immobilized than if a crop with a more quickly established N demand had been used. As indicated in Figures 12 and 13, all of the available soil N was not utilized by 16 weeks. Other researchers have reported the complete removal of available soil N after approximately 4 to 8 weeks by plants such as sudan grass (Stanford, et al., 1973) and tomato and tobacco (Goring and Clark, 1948). The delayed N demand by pineapple is partially explained by the large fraction of the TN_0 that was present in the planting material.

The 16-week dry weight data in Table 19 provides additional evidence that the initial NO_3-N in the Molokai and Wahiawa soils did not significantly benefit early growth. Pineapple at the time of planting is a poor competitor for available N. In the field, one or more months may be required for the establishment of an appreciable root system, and the N already present in the planting material may be adequate for crop establishment. This helps to explain the absence of any effect of 200 lb/ac preplant urea on the growth of pineapple during the first month of a field experiment by Gowing and Klemmer (1961) and a significant residual effect of urea on the later growth of tops and roots in the same experiment. Gowing and Klemmer (1961) concluded that post-plant N fertilizer adequately met the crop requirement and that soil moisture was the most significant determinant of growth during the first month.

It is reasonable to suggest that mineral N levels in the soil assume a major role only after several weeks, and possibly after several months where moisture is the major limiting factor. The

losses of N in the field due to both leaching and immobilization during this period preclude the accurate assessment of available N by simple extraction tests at the time of planting. Soil sampling for NO_3-N at strategic times after planting and a mineralization index determined in the laboratory relative to other field locations may be usefully applied to determine the as yet unknown importance of soil-derived N to pineapple nutrition.

Of further interest, apart from the effects of residue, is the differential effect of soil applied and foliar applied N. It was shown in Chapters IV and V that applied soil N resulted in greater dry weight responses than applied foliar N, while applied foliar N had a localized effect on the leaves which resulted in greater leaf moisture, higher leaf N concentrations, and longer leaves. If the same differential effects occur in the field, the dry weight responses suggest that N applied to the soil is superior to foliar applied N, provided it is not leached or immobilized beyond certain limits. Moreover, the less N that is applied to the leaves during the early stages of growth, the greater would be the N recovery from the soil. Thus, a limited degree of N deficiency might be tolerated as long as available N is not also lacking in the soil and a healthy root system can be maintained. This conclusion is in agreement with the results presented by Sanford (1961), who showed that the rate of N applied and the visual color index used by the industry to determine N status were considerably less important in terms of yields during early stages of growth than during the critical months prior to floral differentiation at 12 to 16 months after planting. These

results also have some bearing on the advent of drip irrigation in the pineapple industry. Applications of N through a drip system following plant establishment may prove to be more efficient on a dry crop weight basis than either preplant soil applications or foliar applications.

VI.B. SOIL N MINERALIZATION WITH RESIDUE INCORPORATION

The large quantities of pineapple residue that accumulate during the crop cycle makes the immediate incorporation of fresh residue into the soil difficult. For this reason, residue is incorporated gradually by periodic disking. Where fields are too dry or the intercycle too short for sufficient decomposition, the usual alternative to residue incorporation is to burn the residue. The following "short-intercycle" alternatives also exist, but are of little if any importance in Hawaii at this date:

1. Since pineapple residue can be used for bromelain extraction (Heinicke and Gortner, 1957) and as an animal-feed supplement (Weyman, et al., 1976), the mechanical removal of the residue from the field has been practiced to some extent. However, mechanical removal entails careful scheduling and increased labor and may be detrimental in some areas to the physical characteristics of the soil owing to compaction.

2. A "trash-mulch" system was investigated in the past in Hawaii which allowed for replanting in the interspaces of windrowed residue. However, the system was abandoned around 1960 since the advantages of early replanting and the conservation of moisture and

nutrients were apparently outweighed by the disadvantages of reduced soil temperatures, increased disease potential, and volunteer regrowth.

3. If pineapple residue could be finely divided in the field at a low-energy cost, it could be more easily incorporated and would decompose more quickly. This is not presently done on a plantation scale in Hawaii for lack of suitable equipment.

The results of the present incubation and glasshouse experiments indicate that the "quick incorporation" of moderate amounts (e.g., 20,000 kg/15 cm ha) of residue in the field would probably immobilize up to 200 kg N/ha. Over a period of time, probably less than a year, nearly the same amount of N would be released back into the soil solution in addition to the expected amount of N mineralized from the native soil organic matter. The net result would not be measurably different from an untreated soil. It is important to note here that both the immobilization effect and the subsequent enhanced mineralization effect of residue incorporation depend upon moist conditions for rapid decomposition. Hence, the intensity of both effects would be minimized by low soil moisture, a frequent occurrence on Hawaiian plantations.

The results in Table 4 indicate that the overall residue effects on the cumulative N mineralized during a crop cycle may not be as great as the variation in N mineralized among different field soils. While no significant N fertilizer value can be ascribed to the residue, the amounts of mineralized N in the field may be significant. Short term studies, such as the present one, cannot

answer the uncertainties of continuous residue removal or incorporation over multiple cycles. However, it can be concluded from the closeness of the mineralization rate index for samples of the same soil (Table 3) that the industry should be able to use a mineralization index to monitor N status for a network of soils. Small changes in mineralizable N over time within the network due to cropping practices such as residue management would be measurable without expensive field research.

The immobilization of N in the rhizosphere resulting from residue incorporation may reduce the amount of N lost by leaching. This would be of obvious advantage if the compensating effect of enhanced N mineralization could be delayed until the N demand by the subsequently planted crop is high. King (1934) accomplished this by immediately following residue incorporation with panicum as an intercrop. Grasses such as panicum have an effective root system for the recovery of additional N from the subsoil and a C:N ratio which lengthens the N immobilization period upon incorporation into the soil. The result in the experiment by King (1934) was that more N was mineralized at a later date following the growth and incorporation of panicum than where pineapple residue incorporation was not followed by panicum and the soil allowed to remain fallow.

It follows from the above arguments that pineapple residue management is likely to have no effect on the N status of the subsequent crop unless one or both of the following are employed: (1) The residue is quickly incorporated immediately prior to planting, in which case the residue-induced immobilization-

mineralization effects would be operative during the early stages of growth. (2) Intercropping is practiced, in which case intercycle management may effectively influence the quantities of mineralizable N over longer periods than when any of the pineapple residue management schemes are employed without intercropping. Neither of these possibilities are of practical concern to the industry at the present time.

VI.C. FERTILIZER N REQUIREMENTS WITH RESIDUE INCORPORATION

It was mentioned above (VI.A.) that several weeks are required after planting for the rooting of pineapple and for the establishment of an N demand. It is obvious from the dry weight response to applied soil N presented in Table 22 that N in the present study was not severely limiting in any of the soils with or without residue until later than 16 weeks. Although the average dry plant weight response to applied soil N was significant at 16 weeks (Table 10), the responses among the 8 soils-by-residue treatments were small and inconsistent (Table 22). No consistent residue effect on the dry weight response to N occurred at 16 weeks because the residue-enhanced soil-plant moisture status and the residue-induced N immobilization had counteractive effects on plant growth.

The increased dry plant weight at 38 weeks due to applied soil N was greater without residue treatment than with residue for the two soils with low levels of initial NO_3-N and greater with residue treatment than without residue for the two soils with high levels of initial NO_3-N (Table 22). This was probably because the immobilization

Table 22

Effect of incorporated residue in each of four soils on the response to applied soil N by pineapple grown for 16 and 38 weeks in the glasshouse.

Soil	Initial NO_3-N	Incorporated Residue	Increased Dry Weight Due to 100 ppm Applied Soil N	
			16 weeks	38 weeks
	(ppm)	(%)	----------(g/plant)----------	
Leilehua	15	0.0	1.4	40.1**
		1.0	6.2^{x}	27.5**
Molokai	105	0.0	3.3	29.5**
		1.0	-0.6	41.0**
Lahaina	20	0.0	1.4	31.3**
		1.0	4.1	19.2**
Wahiawa	105	0.0	3.6	11.9^{x}
		1.0	3.2	29.5**

^{x} and ** denote significant responses at P = 0.10 and 0.01, respectively.

of a large quantity of initial NO_3-N precluded the immobilization of applied soil N. Only mineral N which was not immobilized effected a plant response. In the field, the immobilization of fertilizer N following residue incorporation would be expected to occur to a greater extent in soils with initially low levels of NO_3-N. Allison (1973) commented with regard to this that it is generally considered best to fertilize the crop and not the decomposing residue for the most effective use of fertilizer N.

Between 16 and 38 weeks after planting, when N was the single-most limiting factor, the residue treatment had little, if any, effect on either the plant N concentration or the dry plant weight. Figure 18 illustrates this using the longest leaf to show the small effects of the residue relative to soil and applied NH_4NO_3 over time.

The effect of time is most obvious. While N concentrations dropped rapidly for several treatments soon after planting, they did not drop below 1.0% until after 16 weeks. The rate of dry matter accumulation increased after 16 weeks. The period between 16 and 28 weeks was the period of greatest increasing N demand relative to the dry matter accumulation. Residue incorporation only slightly advanced the period of high relative N demand, and as the quantity of available N became increasingly limited in time, the residue effect became smaller. Even the small difference in N concentrations between the soil-only and the foliar-only treatments was greater than the residue effect in these same treatments (Figure 18c).

Soil had less effect over time than applied N. Yet, the curves for the Leilehua (X) and Lahaina (∇) soils in Figure 18a and d

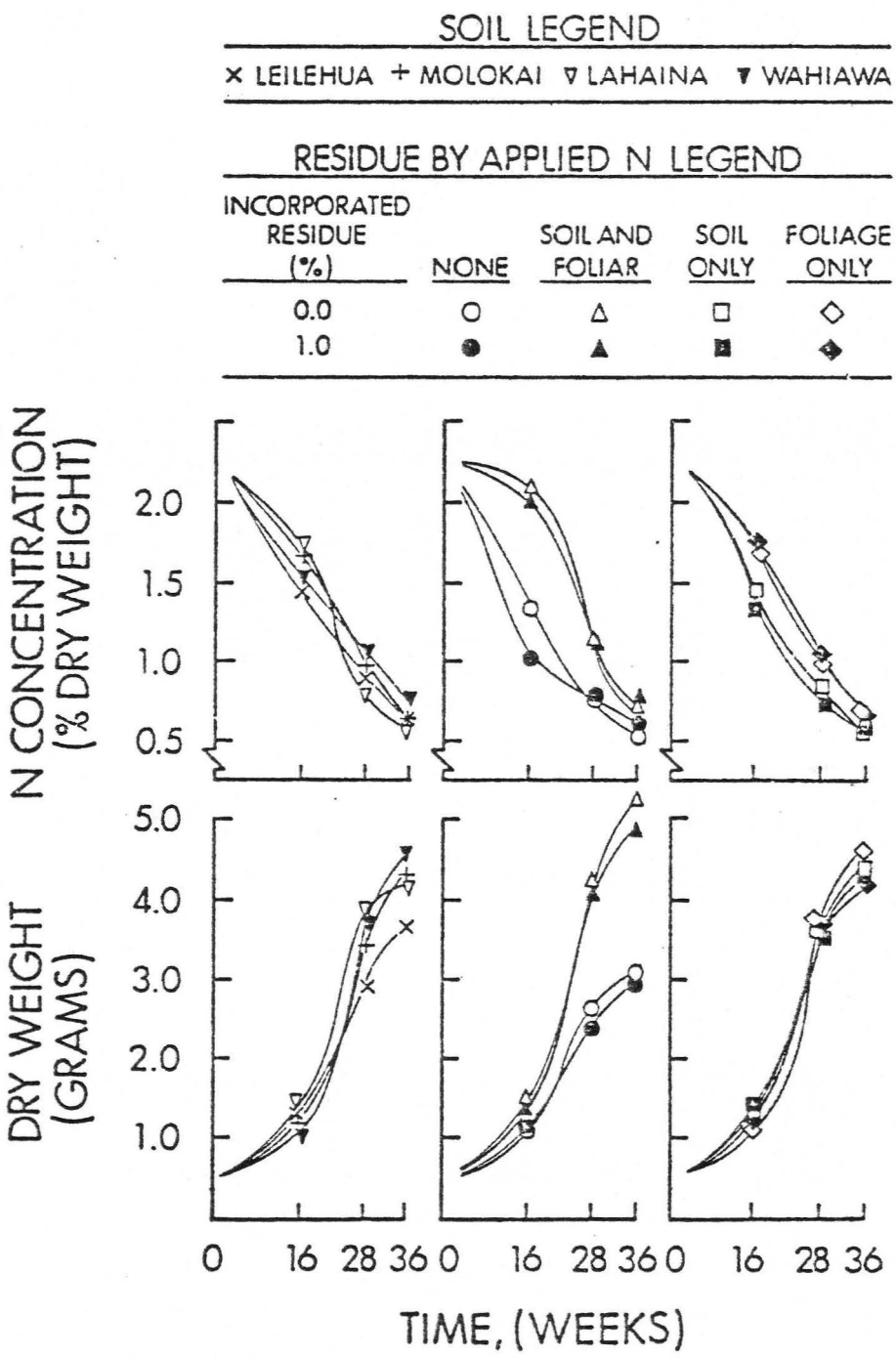

Figure 18. The main effects of 4 soils (residue-by-applied-N-treatments averaged) and the main effects of 8 residue-by-applied-N treatments (soils averaged) on the N concentration and dry weight of the longest leaf over time.

are clearly more divergent than the curves illustrating the greatest residue effects. Initial NO_3-N was low in both soils. Greater amounts of mineralized N (Table 20) and higher base status (Table 1) may explain the greater dry matter accumulation for the Lahaina soil. However, the greater N dilution with time in the Lahaina soil indicates that mineralized N was of minor consequence.

Chapter VII

SUMMARY AND CONCLUSIONS

Quantitative information regarding the effect of incorporated pineapple plant residue on N availability is important to the evaluation of residue management alternatives. In the present studies, residue incorporation was evaluated relative to (1) laboratory-derived mineralization indexes for four soils and (2) pineapple plant responses in the same four soils to soil and foliar applied NH_4NO_3 fertilizer.

When incubated samples were not treated with pineapple residue, the net N mineralized in the laboratory was linear in time from 30 to 210 days. Two mineralization indexes were derived: (1) The mineralization rate from 0 to 210 days, and (2) the net N mineralized at 285 days. Both mineralization indexes suggested that appreciable differences in mineralizable soil N may occur among pineapple fields. The mineralization rate appeared to be the most precise index for soil comparisons owing to both the linear nature of the mineralization curves and the lag or burst in mineralization during the initial 30 days incubation.

After 30 days incubation in the laboratory, soils treated with 1.0% residue on a dry soil weight basis had a deficit of 9 to 61 ppm mineral N relative to untreated samples. There was no significant correlation between the levels of NO_3-N in the individual samples immediately prior to residue treatment and the 30-day N deficit,

although the initial NO_3-N appeared to be closely related to the amount of N immobilized during the first few days of incubation.

The N immobilization brought about by the residue treatment lasted from less than 30 to more than 60 days and was followed by an enhancement of N mineralization relative to respective untreated samples. By 100 to 240 days incubation, depending upon the sample, residue-enhanced N mineralization completely compensated for the earlier immobilized N. The cumulative effect of the residue at 285 days incubation represented a 0 to 30% increase in the net N mineralized over respective samples without residue treatment.

Neither of the laboratory-derived mineralization indexes related well to N uptake by pineapple planted in the same soils in the glasshouse, even for soils with nearly equal levels of initial NO_3-N. Large temperature-moisture fluctuations as well as root confinement in the pots were likely to have minimized the mineralization of soil N in the glasshouse. Additional research is required to assess the importance of the mineralization of native soil N to pineapple under field conditions.

Soil structure and base status appeared to be just as important as the soil N regime to plant growth until 16 weeks after planting. Not until 16 to 38 weeks after planting did high levels (105 ppm) of initial NO_3-N and 100 ppm applied soil N explain most of the increases in leaf length and dry plant weight. It was concluded that under optimum conditions the N demand by pineapple does not become of major importance until two or three months after planting, and after longer periods where water is the major limiting factor.

Nitrogen applied foliarly as NH_4NO_3 resulted in plants with longer leaves and higher leaf moisture contents than when equivalent amounts of NH_4NO_3 were applied to the soil prior to planting. However, N applied to the soil was concluded to be superior to N applied to the leaves because (1) soil applications resulted in greater dry leaf weights despite the greater effect of foliar applied N on leaf length and (2) soil applications increased the dry stem+root weights while foliar applications did not. The superior effect of the soil applied N may have been due to the increased availability of NO_3-N after the nitrification of the ammonium fraction of the NH_4NO_3, although it is also possible that the application of N to the soil improved root health. These results suggested that where frequent applications of foliar N are made by the industry, the beneficial effects of both initial NO_3-N and applied soil N on plant growth may be underestimated or neglected.

Three days after mixing the soil with residue at 1.0%, all the initial NO_3-N in the four soils, ranging from 15 to 105 ppm, was immobilized. However, because of the time required for the development of a N demand by the plant, the residue treatment did not significantly reduce the N uptake from the soil during the first 16 weeks after planting. By 38 weeks after planting, the residue treatment in the two soils having 105 ppm initial NO_3-N effected a reduction in N uptake, while residue treatment in the two soils having 15 or 20 ppm initial NO_3-N had no significant effect on N uptake.

Residue treatment reduced the evaporative losses from pots in the glasshouse and improved the soil-plant moisture regime. This

in turn improved the plant recovery of the following elements in order of decreasing concentration in the leaves: K, Cl, Ca, Si, Mg, P, S. As a soil amendment, there is little doubt that K in the residue is equivalent to fertilizer K and that the improved physical characteristics due to residue incorporation also improve root health. These beneficial effects of residue incorporation may indirectly improve the N recovery by the crop from the soil profile, particularly where improved root distribution enables the recovery of large quantities of N in the subsoil. However, even these direct and indirect benefits of the residue do not compensate for the costs and the logistical problems associated with residue incorporation by the industry.

The effects of residue treatment in this study indicate that residue incorporation in the field would only temporarily immobilize up to 200 kg/ha mineral N in the surface soil. However, it was concluded that pineapple residue management is of negligible importance to the N regime during a pineapple cropping cycle in Hawaii for three reasons: (1) The immobilization effects of the residue in the soil are short-lived relative to the time requirements for land preparation, planting, and the development of a N demand by the crop. (2) Both the short term and the cumulative effects of the residue on available soil N during a single crop cycle are small in comparison to the quantity of available N required to maintain a healthy crop. (3) Residue effects are smaller than the variability normally encountered in plantation agriculture, such as differences due to ammonium versus nitrate fertilizer, foliar versus soil fertilization, and the quantities of mineralized N in different fields.

APPENDIXES

APPENDIX A. RESULTS OF SOIL SURVEY AND PRELIMINARY INCUBATION.

The results of a survey and preliminary incubation study are reported in the following tables for pineapple soils from 27 sites, sugar-cane soils from 5 sites, and uncultivated soils from 16 sites. Each of the sugar-cane and uncultivated sites was selected so as to correspond at the series level of the soil taxonomy to one of the 18 series which were represented by the 27 pineapple soils.

The gracious assistance with the field sampling by John Oshiro of Maui Pineapple Co., Tom Davidson of Dole Pineapple Co., and Ron Francis of Del Monte Corp., and the many hours of conscientious technical assistance by Marcus Pottenger, an undergraduate at the University of Hawaii, are gratefully acknowledged.

A.1. Site Identification

SAMPLE: The soil series symbols of the Soil Conservation Service (1972) were used to identify samples. Where the same series of a given management history was collected from more than one site, Arabic numerals were used following the series symbol to distinguish between sites. Roman numerals were used parenthetically to indicate one (I) or two (II) replicates. Hence, Hbl (I) and Hb2 (I) designate two sites for a Haiku clay for which there were unreplicated samples. Two replicates were obtained at several sites to provide some measure of normal field variability. The maps of the Soil Conservation Service (1972) were used in conjunction with plantation maps to locate the

sampling sites. Site locations for uncultivated soils were immediately adjacent to the pineapple fields of the corresponding soil series. Each sample was taken as a representative composite of surface soil (0 to 15 cm) from one site.

CLASSIFICATION: A reasonably broad and representative distribution of those pineapple soils identified by the Soil Conservation Service (1972) was achieved in the survey. The distribution of sugar cane and uncultivated soils was not as broad or as representative because these soils were sampled on a site specific basis for comparison with individual pineapple soils.

GENERAL LOCATION: Common geographical names were used to identify the general site locations on Oahu (O.) and Maui (M.).

FIELDS: Fields were identified by plantation-assigned numbers extant at the time of sampling.

VEGETATION: For uncultivated soils, the general vegetative characteristics of the sites were reported.

ALTITUDE: Approximate altitudes were obtained from topographic maps.

A.1.a. Identification of pineapple soils from 27 sites representing 8 great soil groups.

SAMPLE		CLASSIFICATION	GENERAL LOCATION	FIELD(S)	ALTITUDE (meters)
		Humoxic tropohumult			
Hb	(II)	Haiku c.	Central Haiku, M.	ML&P 224	230
Hw1	(II)	Honolua s. c.	Honolua, M.	ML&P 56	200
Hw2	(II)		Upper Kahana, M.	ML&P 28	450
Le	(II)	Leilehua s. c.	Upper Waipio, O.	Dole 4201	300
Mf	(II)	Makawao s. c.	Makawao, M.	ML&P 256 & 257	530
Pf	(II)	Pauwela c.	Kakipi, M.	ML&P 211	150
		Orthoxic tropohumult			
Ae1	(I)	Alaeloa s. c.	Central Kahana, M.	ML&P 28	300
Ae2	(I)				250
Ae3	(II)				220
Hl	(II)	Hamakuapoko s. c.	Paia, M.	ML&P 240 & 241	300
Mp	(I)	Manana s. c.	Upper Kipapa, O.	Dole 4131	275
Mo1	(I)	Manana s. c. l.			250
Mo2	(II)		N-west Kunia, O.	Del Monte 4067	225
		Typic torrox			
Kn	(II)	Keahua s. c. l.	Omaopio Road, M.	MLP 295	380
Mu1	(II)	Molokai s. c. l.	Lower Kipapa, O.	Dole 4119	150
Mu2	(I)			Dole "abandoned"	150
		Tropeptic eutrustox			
La	(II)	Lahaina s. c.	Mililani, O.	Dole 4111	150
Wa	(II)	Wahiawa s. c.	Central Kipapa, O.	Dole 4131	200
		Tropeptic haplustox			
Kb	(II)	Kahana s. c.	Lower Kahana, M.	ML&P 29	75
		Ustoxic humitropept			
Hh	(I)	Haliimaile s. c.	Haliimaile, M.	ML&P 263	380
Hg	(II)	Haliimaile s. c. l.	Pukalani, M.	ML&P 273 & 274	525
Ku	(II)	Kolekole s. c. l.	Central Kunia, O.	Del Monte 8037	150
Ky1	(I)	Kunia s. c.	West Kunia, O.	Del Monte 7094	225
Ky2	(II)	Kunia s. c.	Central Kunia, O.	Del Monte 8037	150
		Oxic dystrandept			
Mc	(II)	Mahana s. c. l.	West Kunia, O.	Del Monte 7094	300
		Cumulic haplustoll			
Kl1	(I)	Kawaihapai c. l.	Central Kunia, O.	Del Monte 8037[a]	150
Kl2	(I)			Del Monte 8037[b]	150

[a] Block 42 on west side of gully

[b] Block 37 on east side of gully

A.1.b. Identification of sugar cane soils from 5 sites representing 4 great soil groups.

SAMPLE		CLASSIFICATION	GENERAL LOCATION	FIELD	ALTITUDE
					(meters)
		Typic torrox			
Mu	(II)	Molokai s. c. l.	Waipahu, O.	Along Kunia Rd.	75
		Tropeptic eutrustox			
La	(II)	Lahaina s. c.	Kunia, O.	166 by Kunia Rd.	100
		Ustoxic humitropept			
Ku	(II)	Kolekole s. c. l.	Kunia, O.	275 by Kunia Rd.	150
Ky	(II)	Kunia s. c.	Kunia, O.	275 by Kunia Rd.	150
		Cumulic haplustoll			
Kl	(II)	Kawaihapai c. l.	Kunia, O.	147 north end	125

A.1.c. Identification of uncultivated soils from 16 sites representing 6 great soil groups.

SAMPLE	CLASSIFICATION	GENERAL LOCATION	VEGETATION	ALTITUDE
				(meters)
	Humoxic tropohumult			
Hb1 (I)	Haiku c.	Central Haiku, M.	Grass	230
Hb2 (I)			Shrub	230
Hw (II)	Honolua s. c.	Upper Kahana, M.	Shrub	450
Le1 (I)	Leilehua s. c.	Upper Waipio, O.	Forest	300
Le2 (I)			Litchi	300
Mf (I)	Makawao s. c.	Makawao, M.	Pasture	530
Pf (I)	Pauwela c.	Kakipi, M.	Pasture	150
	Orthoxic tropohumult			
Ae1 (I)	Alaeloa s. c.	Central Kahana, M.	Thicket	300
Ae2 (I)				220
H1 (II)	Hamakuapoko s. c.	Paia, M.	Grass	300
Mo (I)	Manana s. c. l.	Upper Kipapa, O.	Pasture	275
	Typic torrox			
Kn (II)	Keahua s. c. l.	Omaopio Road, M.	Grass	380
	Tropeptic eutrustox			
Wa1 (I)	Wahiawa s. c.	Central Kipapa	Shrub	200
Wa2 (I)			Grass	200
	Tropeptic haplustox			
Kb (II)	Kahana s. c.	Lower Kahana, M.	Shrub	75
	Oxic dystrandept			
Mc (II)	Mahana s. c. l.	West Kunia, O.	Shrub	300

A.2. Base and Organic Matter Status

pH: The pH was determined using a 1:1 soil:water (w:v) mix which was allowed to equilibrate overnight.

1 N NH_4OAc EXTRACTABLE Ca AND K: Extractable bases were determined by atomic absorption spectroscopy after extracting for one hour from 10.0 g soil with 50 cc 1.00 N NH_4OAc (77 g crystalline NH_4OAc/l).

BASE SATURATION: The percent (%) base saturation relative to the effective cation exchange (meq extractable Ca + Mg + K + Na + titratable acidity) was reported. Titratable acidity was determined by the pH change of the above 1.00 N NH_4OAc extraction solution as described by Hesse (1971, pp. 40-41).

ORGANIC CARBON (O.C.): Organic carbon was determined by the Walkley-Black method as described by Allison (1965), but with some modifications as follows: Soils were screened (1.0 mm sieve) and dried at 100°C and weighed into 500 ml erlenmeyer flasks according to their relative carbon content (20 to 40 mg soil organic carbon per flask). Fifteen cc 1.0 N $K_2Cr_2O_7$ was added to each flask and the soil and dichromate solution allowed to stand for several hours. Concentrated sulfuric acid (25 cc) containing 10 g Ag_2SO_4/liter was was added to each flask and the reaction mixture gently swirled and placed on a large preheated hot plate to maintain the high temperature of the reaction for at least one minute with occasional swirling. To avoid the thermal decomposition of dichromate, the reaction mixture was not allowed to bubble or fume excessively and remained on

the hot plate no longer than 2 minutes. Standard solutions of 0, 2.0, 3.0 and 4.0 cc containing 0, 20, 30 and 40 mg C, respectively, as potassium biphthalate ($KHC_8H_4O_4$) were run exactly in the same manner as the samples. The reaction mixtures were allowed to cool and approximately 250 cc tap water was added followed by 10 cc concentrated H_3PO_4. Diphenylamine was added (approximately 2 cc or until achieving a deep purple) immediately before titration with 1.0 N $FeSO_4$.

TOTAL NITROGEN (T.N.): Total N was determined by the semi-micro Kjeldahl method. Soil (500 mg) was weighed into 75 cc Technicon digestion tubes. One to 2 cc distilled water containing 15 g H_2SeO_3/l was added and the soil and selenium solution were allowed to stand for several hours. Concentrated H_2SO_4 (7 cc) was added to each digestion tube followed by 2 to 4 g salt mix (20 K_2SO_4: 2 $CuSO_4$: $FeSO_4$). Using a 40-sample Technicon digestion block, the samples were digested for 3 hours at 200°C followed by 3 hours at 300°C. Where digestion was incomplete, more acid was added and digestion was continued at 300°C. Digestion was considered complete when digestates were a translucent color (yellow to green) and free from anything but the expected white silicate sludge. The digestate was diluted to 75 cc and aliquots containing 0.050 to 0.250 mg NH_4-N were distilled such that the NH_4-N was collected in 100 cc volumetric flasks. Nessler reagent (3 cc per sample) was added after distillation while making the distillates up to volume with distilled water. Along with each set of distillates, standard solutions of 0.050 to 0.250 mg N/100 cc as NH_4Cl were prepared in 100 cc volumetric flasks

with 3 cc Nessler reagent each. Optical densities were measured between 3 and 24 hours later at 435 nm with a 1.0 cm diameter cuvette on a Bausch and Lomb Spectronic 20.

CARBON:NITROGEN RATIO (C/N): The carbon:nitrogen ratio was calculated as O.C./T.N. without correction.

A.2.a. Base and organic matter status for pineapple soils.

SAMPLE	pH	1N NH_4OAc EXTRACTABLE Ca	K	BASE SAT.	O.C.	T.N.	C/N
		--------(%)-------			----(%)----		
Humoxic tropohumult							
Hb (II)	3.9	0.1	0.13	8	2.64	0.20	13.0
Hw1 (II)	5.0	1.3	0.16	54	1.78	0.16	11.4
Hw2 (II)	4.4	0.1	0.15	9	2.44	0.26	9.5
Le (II)	4.0	0.1	0.08	8	2.39	0.23	10.3
Mf (II)	3.9	0.2	0.16	8	3.23	0.32	10.2
Pf (II)	4.4	0.7	0.28	29	3.15	0.26	12.0
Ae1 (I)	4.8	0.7	0.21	22	3.32	0.32	10.5
Ae2 (I)	4.5	0.1	0.16	12	3.96	0.23	17.2
AE3 (II)	4.6	1.8	0.68	46	3.63	0.27	13.3
H1 (II)	4.2	0.7	0.65	26	2.47	0.21	12.0
Mp (I)	4.2	0.1	0.10	10	2.73	0.21	13.1
Mo1 (I)	4.3	0.1	0.17	11	3.16	0.23	13.6
Mo2 (II)	4.4	0.5	0.16	16	5.10	0.34	15.1
Kn (II)	5.8	9.1	1.73	89	2.97	0.20	14.6
Mu1 (II)	4.6	4.1	0.41	70	1.67	0.21	8.0
Mu2 (I)	5.7	4.2	0.43	77	1.44	0.18	7.9
La (II)	5.2	5.4	0.57	69	1.61	0.23	6.9
Wa (II)	4.2	0.2	0.39	18	1.64	0.21	7.7
Kb (II)	4.2	1.3	0.50	43	1.72	0.15	11.6
Hh (I)	4.5	4.2	1.24	64	1.84	0.18	10.1
Hg (II)	4.9	8.9	1.71	78	1.97	0.21	9.4
Ku (II)	4.6	2.8	0.22	58	1.04	0.12	8.7
Ky1 (I)	4.2	1.6	0.34	54	2.55	0.15	17.1
Ky2 (II)	4.2	0.8	0.16	25	1.84	0.21	8.7
Mc (II)	4.0	0.1	0.10	6	4.64	0.33	13.9
Kl1 (I)	6.4	13.1	0.41	95	2.52	0.23	10.9
Kl2 (I)	4.5	4.8	1.48	71	1.96	0.26	7.7
MEAN	4.58	2.5	0.47	40	2.57	0.23	11.3
COEF. OF VARIATION	13%	134%	104%	73%	38%	24%	25%
COEF. OF SKEWNESS	+1.5	+1.7	+1.6	+0.4	+0.8	+0.4	+0.4

A.2.b. Base and organic matter status for sugar cane soils.

SAMPLE	pH	1N NH_4OAc EXTRACTABLE Ca	K	BASE SAT.	O.C.	T.N.	C/N
		---------(%)------			----(%)----		
Typic torrox							
Mu (II)	7.6	13.7	1.24	100	2.02	0.18	11.1
La (II)	5.6	4.8	0.99	81	1.58	0.21	7.4
Ku (II)	4.6	0.9	0.27	35	2.29	0.25	9.1
Ky (II)	4.6	0.8	0.36	38	1.34	0.20	6.7
Kl (II)	6.0	10.5	0.57	88	1.61	0.17	9.2
MEAN	5.68	6.1	0.69	68	1.77	0.20	8.7
COEF. OF VARIATION	22%	94%	60%	44%	22%	16%	20%
COEF. OF SKEWNESS	+0.7	+0.3	+0.4	+0.3	+0.4	+0.6	+0.2

A.2.c. Base and organic matter status for uncultivated soils.

SAMPLE	pH	1N NH_4OAc EXTRACTABLE Ca	K	BASE SAT.	O.C.	T.N.	C/N
		--------(%)--------			----(%)----		
Humoxic tropohumult							
Hb1 (I)	4.0	0.0	0.02	4	3.81	0.30	12.8
Hb2 (I)	5.0	2.3	0.29	56	4.15	0.30	14.5
Hw (II)	5.1	0.8	0.30	43	4.61	0.42	10.9
Le1 (I)	6.3	7.3	0.44	90	3.90	0.36	10.8
Le2 (I)	4.8	1.6	0.17	37	3.50	0.27	13.0
Mf (I)	5.1	1.6	0.28	47	4.08	0.42	9.6
Pf (I)	4.9	0.9	0.23	42	5.19	0.35	14.7
Ae1 (I)	5.6	4.3	1.28	75	3.62	0.31	11.8
Ae2 (I)	6.0	8.7	2.13	88	2.88	0.30	9.5
H1 (II)	6.2	6.4	1.72	85	3.06	0.28	10.8
Mo (I)	5.7	6.7	0.82	75	4.64	0.45	10.4
Kn (II)	6.9	11.5	1.29	96	1.85	0.21	8.8
Wa1 (I)	4.7	2.7	0.57	54	3.38	0.35	9.8
Wa2 (I)	4.1	0.1	0.29	15	2.42	0.28	8.5
Kb (II)	5.3	5.0	1.24	75	3.33	0.30	10.9
Mc (II)	5.0	0.4	0.29	26	5.70	0.37	15.5
MEAN	5.29	3.8	0.71	57	3.76	0.33	11.4
COEF. OF VARIATION	15%	93%	89%	49%	26%	19%	19%
COEF. OF SKEWNESS	+0.3	+0.7	+0.9	+0.3	+0.1	+0.3	+0.6

A.3. Incubation Results Without Residue Treatment

NET N MINERALIZED FROM 0 TO 196 DAYS: The samples were incubated by the procedure described in Chapter III.B., except that (1) 25 g soil per incubation vial was used, (2) serial leachings were made at 0, 4, 16, 36, 64, 100, 144, and 196 days, and (3) the N-free nutrient solution contained 2.0 mM $CaSO_4$, 2.0 mM $MgSO_4$, 5.0 mM $Ca(H_2PO_4)_2$, and 2.5 mM K_2SO_4. The net N mineralized from 0 to t days was designated by ^0N_t, where the superscript denotes no residue treatment. Where replicate samples were involved, these were prepared and incubated separately and the mean $^0N_{196}$ and the standard deviation (s.d.) for the two samples were reported. The $^0N_{196}$ was also reported as the percent (%) of the total soil N.

BEST LINEAR FIT FROM t = 16 TO t = 196 DAYS: The mineralization rate (b) was determined by the slope of the best linear fit of ^0N_t from t = 16 to t = 196 days. The s.d. of b for replicate samples was reported. The closeness of the linear fit was reported as the squared correlation coefficient (r^2). The worst of the two r^2 values was reported for replicated samples. Because ^0N represented a function of t, both b and the positive intercept with the ^0N or t axis can be used to plot the best linear fit. The positive t intercept (t, 0) depicts an initial lag in N mineralization, while the positive ^0N intercept (0, ^0N) depicts an initial burst or enhancement in N mineralization.

A.3.a. Incubation results for pineapple soils without residue treatment.

SAMPLE		NET N MINERALIZED FROM 0 TO 196 DAYS			BEST LINEAR FIT FROM t = 16 TO t = 196 DAYS			
		$^0N_{196}$	s.d.	% of T.N.	b	s.d.	worst r^2	(t, ^0N) intercept
		---(ppm)----			-(ppm/day)			(days/ppm)
Humoxic tropohumult								
Hb	(II)	55	4	3	0.27	0.02	0.99	(0, 4)
Hw1	(II)	57	5	4	0.28	0.04	1.00	(0, 2)
Hw2	(II)	45	6	2	0.24	0.03	1.00	(2, 0)
Le	(II)	60	7	3	0.30	0.05	1.00	(0, 0)
Mf	(II)	75	8	2	0.38	0.05	0.99	(0, 1)
Pf	(II)	89	5	3	0.43	0.02	1.00	(0, 5)
Ae1	(I)	45	--	1	0.22	--	0.99	(0, 1)
Ae2	(I)	32	--	1	0.14	--	0.99	(0, 4)
Ae3	(II)	69	8	3	0.32	0.07	0.99	(0, 6)
Hl	(II)	62	7	3	0.31	0.03	1.00	(0, 1)
Mp	(I)	54	--	3	0.23	--	0.94	(0, 8)
Mo1	(I)	58	--	3	0.28	--	0.99	(0, 4)
Mo2	(II)	47	2	1	0.23	0.00	0.99	(0, 2)
Kn	(II)	62	4	3	0.29	0.03	0.99	(0, 4)
Mu1	(II)	82	6	4	0.39	0.03	1.00	(0, 3)
Mu2	(I)	78	--	4	0.39	--	1.00	(0,13)
La	(II)	85	0	4	0.39	0.03	0.99	(0, 4)
Wa	(II)	109	16	5	0.48	0.06	1.00	(0,13)
Kb	(II)	44	1	3	0.21	0.00	0.98	(0, 2)
Hh	(I)	102	--	6	0.48	--	1.00	(0, 5)
Hg	(II)	89	7	4	0.44	0.04	1.00	(0, 4)
Ku	(II)	37	8	3	0.18	0.05	1.00	(0, 2)
Ky1	(I)	38	--	3	0.15	--	0.99	(0,10)
Ky2	(II)	62	2	3	0.28	0.01	0.99	(0, 4)
Mc	(II)	44	2	1	0.21	0.01	1.00	(0, 4)
Kl1	(I)	52	--	2	0.25	--	1.00	(0, 3)
Kl2	(I)	89	--	3	0.41	--	1.00	(0, 7)
MEAN		64		3.0	0.30			
COEF. OF VARIATION		32%		40%	32%			
COEF. OF SKEWNESS		+0.5		+0.2	+0.3			

A.3.b. Incubation results for sugar cane soils without residue treatment.

SAMPLE	NET N MINERALIZED FROM 0 TO 196 DAYS			BEST LINEAR FIT FROM t = 16 TO t = 196 DAYS			
	$^0N_{196}$	s.d.	% of T.N.	b	s.d.	worst r^2	(t, ^0N) intercept
	---(ppm)----			-(ppm/day)-			(days/ppm)
Typic torrox							
Mu (II)	116	29	6	0.57	0.15	1.00	(0, 5)
La (II)	88	4	4	0.39	0.04	0.97	(0, 7)
Ku (II)	78	19	3	0.38	0.08	0.99	(0, 5)
Ky (II)	78	4	4	0.40	0.02	1.00	(0, 0)
Kl (II)	96	24	6	0.43	0.09	1.00	(0,11)
MEAN	91		4.6	0.43			
COEF. OF VARIATION	17%		29%	18%			
COEF. OF SKEWNESS	+0.8		+0.1	+1.3			

A.3.c. Incubation results for uncultivated soils without residue treatment.

SAMPLE		NET N MINERALIZED FROM 0 TO 196 DAYS			BEST LINEAR FIR FROM t = 16 TO t = 196 DAYS			
		$^0N_{196}$	s.d.	T.N.	b	s.d.	worst r^2	(t, ^0N) intercept
		---(ppm)----			-(ppm/day)-			(days,ppm)
Humoxic tropohumult								
Hb1	(I)	137	--	5	0.82	--	1.00	(32, 0)
Hb2	(I)	204	--	7	0.94	--	1.00	(0,23)
Hw	(II)	200	63	5	0.97	0.28	1.00	(0, 3)
Le1	(I)	282	--	8	1.49	--	0.99	(3, 0)
Le2	(I)	92	--	3	0.44	--	1.00	(0, 6)
Mf	(I)	203	--	5	0.96	--	1.00	(0,16)
Pf	(I)	153	--	4	0.80	--	0.97	(16, 0)
Ae1	(I)	175	--	6	0.89	--	0.99	(7, 0)
Ae2	(I)	241	--	8	1.12	--	0.99	(0, 1)
H1	(II)	185	35	7	0.97	0.11	0.99	(9, 0)
Mo	(I)	224	--	5	1.06	--	0.99	(6, 0)
Kn	(II)	126	21	6	0.67	0.11	0.99	(2, 0)
Wa1	(I)	210	--	6	1.03	--	0.99	(0,17)
Wa2	(I)	103	--	4	0.53	--	0.99	(4, 0)
Kb	(II)	274	73	9	1.37	0.34	0.99	(0, 2)
Mc	(II)	59	32	2	0.33	0.18	0.97	(21, 0)
MEAN		179		5.6	0.90			
COEF. OF VARIATION		36%		34%	34%			
COEF. OF SKEWNESS		-0.2		-0.1	0.0			

A.4. Incubation Results with 1.0% Residue Treatment

NET N MINERALIZED FROM 0 TO 196 DAYS: The samples were prepared with the addition of 1.0% (dry soil weight basis) ground pineapple residue containing 1.0% N. The samples were incubated simultaneously and in like manner with the untreated samples. The net N mineralized from 0 to t days was designated by $^{r}N_{t}$, where the superscript denotes residue. The $^{r}N_{196}$ and s.d. were reported as for $^{0}N_{196}$. The $^{r}N_{196}$ was also reported as a percent (%) of $^{0}N_{196}$ to indicate the relative cumulative effect of the residue.

BEST LINEAR FIT SUBSEQUENT TO t_{lag}: Treating the soil with 1.0% residue brought about an initial immobilization period (designated t_{lag}) which was determined as the t intercept of the best linear fit of ^{r}N as a function of 5. Again, the closeness of the linear fit was reported as the squared correlation coefficient (r^2), except where the immobilization period, and hence the t intercept, was greater than 100 days, in which case only two points (t = 144 and 196 days) were used to fit the curve.

A.4.a. Incubation results for pineapple soils treated with ground pineapple plant residue at 1.0% on a dry soil weight basis.

SAMPLE		NET N MINERALIZED FROM 0 TO 196 DAYS			BEST LINEAR FIT SUBSEQUENT TO t_{lag}			
		r_{N196}	s.d.	% of $^{0}N_{196}$	b	s.d.	worst r^2	t_{lag}
		---(ppm)----			-(ppm/day)-			(days)
Hb	(II)	51	8	93	0.41	0.05	0.98	71
Hw1	(II)	67	7	117	0.45	0.00	0.99	50
Hw2	(II)	39	8	87	0.32	0.02	1.00	74
Le	(II)	44	10	74	0.37	0.02	0.99	79
Mf	(II)	73	10	98	0.49	0.01	0.99	45
Pf	(II)	111	11	124	0.61	0.06	0.99	7
Ae1	(I)	37	--	83	0.34	--	1.00	88
Ae2	(I)	16	--	51	0.15	--	0.96	90
Ae3	(II)	89	21	129	0.49	0.15	0.99	10
H11	(II)	72	6	116	0.48	0.00	1.00	47
Mp	(I)	49	--	90	0.36	--	0.98	62
Mo1	(I)	47	--	81	0.34	--	0.98	62
Mo2	(II)	32	7	67	0.31	0.07	1.00	96
Kn	(II)	124	2	200	0.63	0.01	0.98	6
Mu1	(II)	88	5	108	0.62	0.00	1.00	54
Mu2	(I)	68	--	87	0.60	--	1.00	83
La	(II)	73	8	86	0.55	0.01	0.99	69
Wa	(II)	109	13	100	0.67	0.07	0.99	37
Kb	(II)	74	16	169	0.38	0.05	0.98	6
Hh	(I)	160	--	156	0.77	--	1.00	6
Hg	(II)	130	5	146	0.71	0.05	0.98	6
Ku	(II)	36	11	97	0.29	0.03	0.96	77
Ky1	(I)	59	--	152	0.38	--	1.00	8
Ky2	(II)	67	5	108	0.48	0.00	0.98	65
Mc	(II)	29	6	65	0.34	0.03	--	110
K11	(I)	66	--	127	0.50	--	1.00	65
K12	(I)	112	--	125	0.66	--	1.00	35
MEAN		71.19		108.74	0.47			52.15
COEF. OF VARIATION		49%		32%	32%			62%
COEF. OF SKEWNESS		+0.7		+0.7	+0.1			-0.2

A.4.b. Incubation results for sugar cane soils treated with ground pineapple plant residue at 1.0% on a dry soil weight basis.

SAMPLE	NET N MINERALIZED FROM 0 TO 196 DAYS			BEST LINEAR FIT SUBSEQUENT TO t_{lag}			
	r_{N196}	s.d.	% of $^{0}N_{196}$	b	s.d.	worst r^2	t_{lag}
	---(ppm)----			-(ppm/day)-			(days)
Mu (II)	113	46	98	0.79	0.24	0.97	51
La (II)	106	7	120	0.71	0.08	1.00	48
Ku (II)	77	22	99	0.52	0.11	0.99	45
Ky (II)	81	3	104	0.57	0.02	1.00	56
Kl (II)	118	34	123	0.67	0.08	0.98	19
MEAN	99.00		108.80	0.65			43.80
COEF. OF VARIATION	19%		11%	17%			33%
COEF. OF SKEWNESS	-0.3		+0.3	0.0			-1.2

A.4.c. Incubation results for 16 samples of uncultivated soils treated with ground pineapple plant residue at the rate of 1.0% on a dry soil weight basis.

SAMPLE		NET N MINERALIZED FROM 0 TO 196 DAYS			BEST LINEAR FIT SUBSEQUENT TO t_{lag}			
		r_{N196}	s.d.	% of $^{0}N_{196}$	b	s.d.	worst r^2	t_{lag}
		---(ppm)----			-(ppm/day)-			(days)
Hb1	(I)	125	--	91	0.88	--	0.99	58
Hb2	(I)	165	--	81	0.89	--	1.00	9
Hw	(II)	201	71	101	1.21	0.32	1.00	32
Le1	(I)	261	--	93	1.71	--	0.99	37
Le2	(I)	82	--	89	0.48	--	0.97	43
Mf	(I)	201	--	99	1.22	--	0.99	28
Pf	(I)	161	--	105	1.01	--	0.99	43
Ae1	(I)	190	--	108	1.27	--	1.00	47
Ae2	(I)	276	--	115	1.66	--	0.99	34
H11	(II)	193	30	104	1.28	0.22	1.00	45
Mo	(I)	226	--	101	1.51	--	0.99	55
Kn	(II)	148	11	118	0.95	0.03	1.00	40
Wa1	(I)	232	--	110	1.40	--	0.99	17
Wa2	(I)	84	--	81	0.63	--	0.99	64
Kb	(II)	326	90	119	1.74	0.44	0.99	8
Mc	(II)	35	25	60	0.35	0.26	--	100
MEAN		181.63		98.44	1.14			41.25
COEF. OF VARIATION		42%		16%	37%			54%
COEF. OF SKEWNESS		-0.1		-0.8	-0.3			+0.8

APPENDIX B. ANALYSES OF VARIANCE FOR THE TEN-MONTH INCUBATION EXPERIMENT:

B.1. Analyses of variance for the N mineralization rate from 30 to 210 days (Table 3)

		WITHOUT RESIDUE	WITH 1.0% RESIDUE
GRAND MEAN (ppm/day)		0.60	0.88
COEF. OF VARIATION (% of grand mean)		4.4	4.2
SOURCE	(degrees freedom)	-------(mean square)--------	
Error	8	1	1
Samples	7	38**	105**

** denotes significance at P = 0.01.

B.2. Analyses of variance for the net N mineralized at 285 days (Table 4)

		WITHOUT RESIDUE	WITH 1.0% RESIDUE
GRAND MEAN (ppm)		147	165
COEF. OF VARIATION (% of grand mean)		4.7	4.5
SOURCE	(degrees freedom)	-------(mean square)--------	
Error	8	47	55
Samples	7	3627**	4347**

** denotes significance at P = 0.01.

APPENDIX C. ANALYSES OF VARIANCE FOR THE FOUR-MONTH GLASSHOUSE EXPERIMENT:

Note that the treatments were not replicated for determinations of N in the longest leaf (Appendixes C.1. and C.5.) nor for the moisture and element determinations in the remaining leaves (Appendix C.3.). In these cases, the foliar interactions were deemed "error" in lieu of the replicate interactions.

C.1. Analyses of variance for plant N concentrations at 16 weeks (Table 7).

SOURCE	DEGREES FREEDOM	MEAN SQUARE[1]		
		leaves		
		longest	remaining	stem+roots
		(10^{-3})		
ERROR[2]	15	100	--	--
	62	--	12	22
REPLICATES[3]	2		54*	9
TREATMENTS[3]	16	274		
	31	--	150**	45**
MAIN EFFECTS[3]				
Soil	3	124	73**	85*
Residue	1	75	119**	223**
App. Soil N	1	537*	833**	407**
Foliar N	1	3111**	3139**	270**
INTERACTIONS[3]				
Soil x Resi	3	65	21	17
Soil x Apps	3	1	3	20
Soil x Foli	3	--	11	3
Resi x Apps	1	21	66*	11
Resi x Foli	1	--	38x	0
Apps x Foli	1		0	3
RXAXF	1	--	45x	8
SXAXF	3	--	4	6
SXRXF	3	--	6	8
SXRXA	3	21	9	21
SXRXAXF	3	--	4	3

[1] Actual magnitude of mean square is given by the value in parentheses ().

[2] Foliar interactions were deemed "error" where treatments were unreplicated.

[3] x and * and ** denote significance at P = 0.10 and 0.05 and 0.01, respectively.

C.2. Analyses of variance for leaf length and growth index (Table 8).

SOURCE	DEGREES FREEDOM	MEAN SQUARE[1]		
		Length Longest Leaf		
		14 weeks	16 weeks	Growth Index
		--------(1)--------		---(10^{-3})---
ERROR	62	8	8	385
REPLICATES[2]	2	99**	33*	18132**
TREATMENTS[2]	31	10	18**	2755**
MAIN EFFECTS[2]				
Soil	3	4	9	1423*
Residue	1	6	20	4815**
App. Soil N	1	155**	191**	1898*
Foliar N	1	41*	155**	36138**
INTERACTIONS[2]				
Soil x Resi	3	1	3	1480*
Soil x Apps	3	2	5	833
Soil x Foli	3	4	7	1059*
Resi & Apps	1	0	0	143
Resi x Foli	1	0	0	1238^{X}
Apps x Foli	1	3	1	6151**
RXAXF	1	0	0	1475^{X}
SXAXF	3	8	9	2849**
SXRXF	3	1	1	202
SXRXA	3	1	1	224
SXRXAXF	3	15	30^{X}	3110**

[1] Actual magnitude of mean square is given by the value in parentheses ().

[2] X and * and ** denote significance at P = 0.10 and 0.05 and 0.01, respectively.

C.3. Analyses of variance for leaf moisture and base element concentrations on a leaf moisture basis excluding the longest leaf (Table 9).

SOURCE	DEGREES FREEDOM	MEAN SQUARE[1]				
		Moisture	K	Ca	Mg	Na
		(10^{-3})	(10^{+3})	(1)		
ERROR[2]	15	959	33	846	454	17
TREATMENTS[3]	16	3391**	43	1570	470	60**
MAIN EFFECTS[3]						
Soil	3	1773	134*	2125^{x}	728	6
Residue	1	28940**	115^{x}	2	9	491**
App. Soil N	1	3003^{x}	0	5338*	213	19
Foliar N	1	8052*	37	594	313	209**
INTERACTIONS[3]						
Soil x Resi	3	1080	18	1096	612	18
Soil x Apps	3	1384	2	815	369	37
Resi x Apps	1	237	51	6423*	1702^{x}	0
SXRXA	3	436	6	219	54	20

[1] Actual magnitude of mean square is given by the value in parentheses ().

[2] Foliar interactions were deemed "error" in lieu of replicate interactions.

[3] x and * and ** denote significance at P = 0.10 and 0.05 and 0.01, respectively.

C.4. Analyses of variance for dry plant weight at 16 weeks (Table 10).

SOURCE	DEGREES FREEDOM	MEAN SQUARE			
			leaves		
		whole plant	longest	remaining	stem+roots
ERROR	62	22	31	11	5
REPLICATES	2	204**	242**	114**	37**
TREATMENTS	31	28	105**	17	7
MAIN EFFECTS					
Soil	3	49^{x}	201**	18	37**
Residue	1	109	18	33^{x}	21*
App. Soil N	1	191**	940**	199**	2
Foliar N	1	52	271**	61*	1
INTERACTIONS					
Soil x Resi	3	30	67^{x}	15	3
Soil x Apps	3	7	68^{x}	2	1
Soil x Foli	3	15	9	8	1
Resi x Apps	1	4	88^{x}	3	0
Resi x Foli	1	7	8	1	2
Apps x Foli	1	10	3	0	15^{x}
RXAXF	1	5	38	0	3
SXAXF	3	20	86*	10	1
SXRXF	3	4	115*	3	4
SXRXA	3	22	59	7	6
SXRXAXF	3	16	22	15	0

^{x} and * and ** denote significance at P = 0.10 and 0.05 and 0.01, respectively.

C.5. Analyses of variance for total plant N content and the N content of three plant fractions (Table 11).

SOURCE	DEGREES FREEDOM	MEAN SQUARE[1]			
			leaves		
		whole plant	longest	remaining	stem+roots
		(10^3)	(1)	(10^3)	(1)
ERROR[2]	15	--	19	--	--
	62	4	--	3	310
REPLICATES[3]	2	18*	--	7	4054**
TREATMENTS[3]	16	--	71	--	--
	31	40**	--	29**	772**
MAIN EFFECTS[3]					
Soil	3	6	9	9*	1252*
Residue	1	7	13	4	314
App. Soil N	1	389**	354**	258**	6939**
Foliar N	1	727**	681**	564**	3252**
INTERACTIONS[3]					
Soil x Resi	3	3	5	2	500
Soil x Apps	3	4	10	1	1073*
Soil x Foli	3	5	--	3	286
Resi x Apps	1	5	3	7	258
Resi x Foli	1	2	--	3	123
Apps x Foli	1	0	--	2	1299*
RXAXF	1	16x	--	8	893x
SXAXF	3	3	--	3	120
SXRXF	3	1	--	1	83
SXRXA	3	0	3	0	130
SXRXAXF	3	3	--	3	172

[1] Actual magnitude of mean square is given by the value in parentheses ().

[2] Foliar interactions were deemed "error" where treatments were unreplicated.

[3] x and * and ** denote significance at P = 0.10 and 0.05 and 0.01, respectively.

C.6. Analyses of variance for N recovery (Table 12).

SOURCE	DEGREES FREEDOM	MEAN SQUARE[1]		
		Estimated N-Uptake By Plant	Final Extractable NO_3-N	Apparent Recovery
		---------(10^3)----------		(1)
ERROR	62	4	2	103
REPLICATES[2]	2	9	8*	312[x]
TREATMENTS[2]	31	40**	18**	323**
MAIN EFFECTS[2]				
Soil	3	8	81**	1063**
Residue	1	7	66**	1390**
App. Soil N	1	389**	75**	1628**
Foliar N	1	727**	39**	299[x]
INTERACTIONS[2]				
Soil x Resi	3	3	14**	458**
Soil x Apps	3	4	6*	226[x]
Soil x Foli	3	5	7*	48
Resi x Apps	1	5	0	17
Resi x Foli	1	2	7[x]	91
Apps x Foli	1	0	0	176
RXAXF	1	16[x]	1	66
SXAXF	3	3	1	76
SXRXF	3	2	1	42
SXRXA	3	0	5[x]	143
SXRXAXF	3	3	3	62

[1] Actual magnitude of mean square is given by the value in parentheses ().

[2] [x] and * and ** denote significance at P = 0.10 and 0.05 and 0.01, respectively.

APPENDIX D. MAIN EFFECTS AND ANALYSES OF VARIANCE FOR MACROELEMENT CONCENTRATIONS AT 16 WEEKS AND N CONCENTRATIONS AT 38 WEEKS.

D.1.a. Main effects of soil, pineapple residue, and N fertilizer on macroelement concentrations in the longest leaf at 16 weeks.

	K	Cl	Ca	Si	Mg	P	S
	(% of dry weight)						
SOIL[1]							
Leilehua	3.50b	1.77ab	0.466b	0.261d	0.369ab	0.240a	0.152a
Molokai	3.73b	1.82a	0.487b	0.385b	0.387a	0.239a	0.169a
Lahaina	4.29a	1.82a	0.685a	0.492a	0.325c	0.234a	0.170a
Wahiawa	4.13a	1.68b	0.395c	0.331c	0.337bc	0.233a	0.165a
INCORPORATED RESIDUE[2]							
0.0%	3.64	1.64	0.496	0.333	0.340	0.232	0.150
1.0%	4.19**	1.91**	0.521	0.402**	0.369*	0.241*	0.178**
APPLIED SOIL N[2]							
000 mg	4.17**	1.85**	0.496	0.402**	0.367[X]	0.252**	0.170[X]
250 mg	3.66	1.69	0.521	0.333	0.342	0.220	0.158
APPLIED FOLIAR N[2]							
000 mg	4.05*	1.83**	0.514	0.389*	0.359	0.246**	0.159
250 mg	3.78	1.72	0.502	0.345	0.351	0.227	0.169
	(% of dry weight)						
GRAND MEAN	3.91	1.77	0.508	0.367	0.355	0.236	0.164
	(% of grand mean)						
COEFFICIENT OF VARIATION	7.3	6.2	10.3	11.5	10.5	4.5	10.5

[1] Values for soils in the same column and followed by the same letter are not significantly different at P = 0.05.

[2] [X] and * and ** denote significantly greater values at P = 0.10 and 0.05 and 0.01, respectively.

D.1.b. Analyses of variance for macroelement concentrations in the longest leaf at 16 weeks.

SOURCE	DEGREES FREEDOM	MEAN SQUARE[1]						
		K	Cl	Ca	Si	Mg	P	S
		----(10^{-2})---		--------(10^{-3})--------			---(10^{-4})----	
ERROR[2]	15	8	1	3	2	1	1	3
TREATMENTS[3]	16	60**	8**	28**	24**	3^{X}	10**	8*
MAIN EFFECTS[3]								
Soil	3	107**	3^{X}	120**	76**	6*	1	5
Residue	1	243**	61**	5	38**	7*	6*	63**
App. Soil N	1	209**	21**	5	13**	5^{X}	85**	11^{X}
Foliar N	1	59*	11**	1	15*	1	28**	7
INTERACTIONS[3]								
Soil x Resi	3	12	4^{X}	0	2	1	3^{X}	2
Soil x Apps	3	9	1	12*	1	3	2	1
Resi x Apps	1	63*	5^{X}	17*	35**	4	15**	11^{X}
SXRXA	3	1	0	2	3	0	2	2

[1] Actual magnitude of mean square is given by the value in parentheses ().

[2] Foliar interactions were deemed "error" since replicate leaves for each treatment were pooled for chemical analyses.

[3] ^{X} and * and ** denote significance at P = 0.10 and 0.05 and 0.01, respectively.

D.2.a. Main effects of soil, pineapple residue, and N fertilizer on macroelement concentrations in the leaves (longest leaf excluded) at 16 weeks.

	K	Cl	Ca	Si	Mg	P	S
	(% of dry weight)						
SOIL[1]							
Leilehua	2.12b	1.27a	0.407b	0.364b	0.376a	0.180a	0.125b
Molokai	2.11b	1.30a	0.410b	0.381b	0.370a	0.181a	0.130b
Lahaina	2.69a	1.37a	0.495a	0.462a	0.356a	0.187a	0.154a
Wahiawa	2.40ab	1.28a	0.395b	0.377b	0.361a	0.177a	0.135b
INCORPORATED RESIDUE[2]							
0.0%	2.06	1.17	0.397	0.360	0.340	0.175b	0.123
1.0%	2.61**	1.44**	0.457**	0.432**	0.392**	0.188a	0.149**
APPLIED SOIL N[2]							
000 mg	2.28	1.27	0.393	0.398	0.354	0.183a	0.131
250 mg	2.38	1.35	0.460**	0.394	0.378^{x}	0.180a	0.141^{x}
APPLIED FOLIAR N[2]							
000 mg	2.31	1.28	0.403	0.394	0.358	0.188a	0.126
250 mg	2.36	1.33	0.451*	0.398	0.374	0.175b	0.146**
	(% of dry weight)						
GRAND MEAN	2.33	1.31	0.427	0.396	0.366	0.182	0.136
	(% of grand mean)						
COEFFICIENT OF VARIATION	14.3	11.4	11.5	14.5	10.7	7.4	12.2

[1] Values for soils in the same column and followed by the same letter are not significantly different at P = 0.05.

[2] ^{x} and * and ** denote significantly greater value(s) at P = 0.10, 0.05 and 0.01, respectively.

D.2.b. Analyses of variance for macroelement concentrations in the leaves (longest leaf excluded) at 16 weeks.

SOURCE	DEGREES FREEDOM	MEAN SQUARE[1]						
		K	Cl	Ca	Si	Mg	P	S
		---(10^{-2})----		-------(10^{-3})--------			---(10^{-4})----	
ERROR[2]	15	11	2	2	3	2	2	3
TREATMENTS[3]	16	31*	5*	11**	8^{x}	3	4^{x}	10*
MAIN EFFECTS[3]								
Soil	3	90*	2	17**	16*	1	1	13*
Residue	1	241**	60**	29**	42**	22**	14*	53**
App. Soil N	1	7	5	36**	0	5^{x}	1	9^{x}
Foliar N	1	2	2	19*	0	2	14*	30**
INTERACTIONS[3]								
Soil x Resi	3	3	1	1	3	1	3	0
Soil x Apps	3	7	2	4	0	0	1	0
Resi x Apps	1	23	3	21**	14^{x}	6^{x}	3	14*
SXRXA	3	5	0	2	3	1	4	3

[1] Actual value of mean square is given by the value in parentheses ().

[2] Foliar interactions were deemed "error" since the chemical analyses were conducted on a single replicate.

[3] ^{x} and * and ** denote significance at P = 0.10 and 0.05 and 0.01, respectively.

D.3.a. Main effects of soil, pineapple residue, and N fertilizer on N concentrations in the top and bottom fractions of the plant at 38 weeks.

	TOP	BOTTOM
	--(% of dry weight)---	
SOIL[1]		
Leilehua	0.77b	0.53b
Molokai	0.82ab	0.56ab
Lahaina	0.71c	0.54b
Wahiawa	0.87a	0.59a
INCORPORATED RESIDUE[2]		
0.0%	0.78	0.54
1.0%	0.81	0.57x
APPLIED SOIL N[2]		
000 mg	0.75	0.53
400 mg	0.84**	0.58**
APPLIED FOLIAR N[2]		
000 mg	0.67	0.50
400 mg	0.91**	0.61**
	--(% of dry weight)---	
GRAND MEAN	0.79	0.56
	--(% of grand mean)---	
COEFFICIENT OF VARIATION	11.6	12.7

[1] Values for soils in the same column and followed by the same letter are not significantly different at P = 0.05.

[2] x and * and ** denote significantly greater value(s) at P = 0.10, 0.05 and 0.01, respectively.

D.3.b. Analyses of variance for N concentrations in the top and bottom fractions of the plant at 38 weeks.

SOURCE	DEGREES FREEDOM	MEAN SQUARE[1]	
		TOP	BOTTOM
		--------(10^{-3})--------	
ERROR	62	8	5
REPLICATES	2	6	10
TREATMENTS[2]	31	58**	20**
MAIN EFFECTS[2]			
Soil	3	115**	14*
Residue	1	18	17[x]
App. Soil N	1	219**	75**
Foliar N	1	1380**	304**
INTERACTIONS[2]			
Soil x Resi	3	37**	19*
Soil x Apps	3	19[x]	2
Soil x Foli	3	7	2
Resi x Apps	1	1	0
Resi x Foli	1	0	5
Apps x Foli	1	2	9
RXAXF	1	7	19
SXAXF	3	7	6
SXRXF	3	5	4
SXRXA	3	27*	12[x]
SXRXAXF	3	7	10

[1] Actual magnitude of mean square is given by value in parentheses().

[2] [x] and * and ** denote significance at P = 0.10 and 0.05 and 0.01, respectively.

APPENDIX E. ANALYSES OF VARIANCE FOR THE TEN-MONTH GLASSHOUSE EXPERIMENT.

E.1. Analyses of variance for the N concentration in the longest leaf at 28 and 36 weeks (Table 15).

SOURCE	DEGREES FREEDOM	MEAN SQUARE[1]	
		28 weeks	36 weeks
		(10^{-3})	
ERROR	62	8	5
REPLICATES	2	6	10
TREATMENTS[2]	31	58**	20**
MAIN EFFECTS[2]			
Soil	3	115**	14*
Residue	1	18	17[x]
App. Soil N	1	219**	75**
Foliar N	1	1380**	304**
INTERACTIONS[2]			
Soil x Resi	3	37**	19*
Soil x Apps	3	19[x]	2
Soil x Foli	3	7	2
Resi x Apps	1	1	0
Resi x Foli	1	0	5
Apps x Foli	1	2	9
RXAXF	1	7	19[x]
SXAXF	3	7	6
SXRXF	3	5	4
SXRXA	3	27*	12[x]
SXRXAXF	3	7	10

[1] Actual magnitude of mean square is given by value in parentheses ().

[2] [x] and * and ** denote significance at P = 0.10 and 0.05 and 0.01,

E.2. Analyses of variance for the length of the longest leaves at 14, 16, 20, 28, and 36 weeks (Table 16).

SOURCE	DEGREES FREEDOM	MEAN SQUARE				
		Attached Leaves			Pulled Leaves	
		14 weeks	16 weeks	20 weeks	28 weeks	36 weeks
ERROR	62	9.68	9.82	10.30	12.71	11.20
REPLICATES	2	6.11	9.69	12.05	3.78	25.03
TREATMENTS	31	27.08**	38.89**	61.19**	79.97**	92.62**
MAIN EFFECTS						
Soil	3	38.39*	76.88**	153.39**	194.56**	139.13**
Residue	1	1.45	0.84	0.00	3.34	1.35
App. Soil N	1	502.33**	677.34**	732.61**	365.43**	697.68**
Foliar N	1	1.45	35.04^{X}	380.01**	986.24**	1241.28**
INTERACTIONS						
Soil x Resi	3	17.83	19.97	3.60	8.50	18.19
Soil x Apps	3	14.77	9.34	8.92	24.37	34.66*
Soil x Foli	3	13.41	22.85^{X}	35.52*	39.10**	51.91**
Resi x Apps	1	5.04	11.34	3.60	5.09	6.61
Resi x Foli	1	10.80	29.93^{X}	28.17	24.10	2.80
Apps x Foli	1	1.50	12.91	51.04*	85.32*	72.45*
RXAXF	1	2.67	1.60	8.28	0.56	3.60
SXAXF	3	6.62	2.38	2.67	7.49	3.46
SXRXF	3	1.09	2.68	5.67	15.38	8.63
SXRXA	3	5.55	7.18	18.72	12.23	16.71
SXRXAXF	3	6.72	4.23	2.55	14.22	9.14

^{X} and * and ** denote significance at P = 0.10 and 0.05 and 0.01, respectively.

E.3. Analyses of variance for the dry plant weight (Table 17).

SOURCE	DEGREES FREEDOM	MEAN SQUARE[1]				
		Total Including Pulled Leaves	Pulled Leaves	Top	Bottom	Top:Bottom Ratio
		$-(10^{+2})-$	----------(1)----------			$-(10^{-3})-$
ERROR	62	1	1	69	30	93
REPLICATES[2]	2	1	0	47	95*	303*
TREATMENTS[2]	31	16**	8**	965**	75**	484**
MAIN EFFECTS[2]						
Soil	3	29**	13**	1666**	189**	857**
Residue	1	31**	3*	1093**	453**	5
App. Soil N	1	198**	76**	12960**	332**	4825**
Foliar N	1	86**	85**	6667**	4	5223**
INTERACTIONS[2]						
Soil x Resi	3	2	0	146	28	139
Soil x Apps	3	3[x]	1[x]	147	41	51
Soil x Foli	3	6**	2*	274*	52	80
Resi x Apps	1	0	0	16	43	40
Resi x Foli	1	2	0	156	4	189
Apps x Foli	1	11**	11**	551**	33	217
RXAXF	1	1	0	7	83	294[x]
SXAXF	3	2	1	93	46	77
SXRXF	3	3[x]	1	138	48	66
SXRXA	3	4*	2[x]	152[x]	44	66
SXRXAXF	3	2	1	205*	4	66

[1] Actual magnitude of mean square is given by value in parentheses ().

[2] [x] and * and ** denote significance at P = 0.10 and 0.05 and 0.01, respectively.

E.4. Analyses of variance for N recovery at 38 weeks (Table 18).

SOURCE	DEGREES FREEDOM	MEAN SQUARE[1]	
		Estimated N-Uptake By Plant	Apparent Recovery
		--(10^3)--	--(1)---
ERROR	62	4	57
REPLICATES	2	3	64
TREATMENTS[2]	31	232**	641**
MAIN EFFECTS[2]			
Soil	3	384**	3133**
Residue	1	72**	483**
App. Soil N	1	2322**	2166**
Foliar N	1	3365**	112
INTERACTIONS[2]			
Soil x Resi	3	55**	720**
Soil x Apps	3	3	402**
Soil x Foli	3	12*	495**
Resi x Apps	1	1	9
Resi x Foli	1	6	79
Apps x Foli	1	4	555**
RXAXF	1	2	38
SXAXF	3	9[X]	223*
SXRXF	3	3	101
SXRXA	3	7	249**
SXRXAXF	3	5	153[X]

[1] Actual magnitude of mean square is given by value in parentheses ().

[2] X and * and ** denote significance at P = 0.10 and 0.05 and 0.01, respectively.

APPENDIX F. MAIN EFFECTS AND ANALYSES OF VARIANCE FOR APPARENT NET N MINERALIZED IN FALLOW POTS AT 16 AND 38 WEEKS.

F.1. Main effects of soil, pineapple residue, and N fertilizer on the apparent net N mineralized in fallow pots.

	16 Weeks	38 Weeks
	(ppm dry soil weight basis)	
SOIL[1]		
Leilehua	-6.6b	9.6b
Molokai	-32.7d	-6.3c
Lahaina	10.8a	44.0a
Wahiawa	-24.2c	11.1b
INCORPORATED RESIDUE[2]		
0.0%	4.2**	25.6**
1.0%	-30.6	3.5
APPLIED SOIL N[2]		
000 ppm	-3.2**	22.5**
100 ppm	-23.2	6.6
	(ppm dry soil weight basis)	
GRAND MEAN	-13.2	14.5
	-----(% of grand mean)-----	
COEFFICIENT OF VARIATION	94.6	72.8

[1] Values for soils in the same column were all significantly different from each other at P = 0.05.

[2] ** denotes significantly greater values at P = 0.01.

F.2. Analyses of variance for apparent net N mineralized in fallow pots.

SOURCE	DEGREES FREEDOM	MEAN SQUARE	
		16 Weeks	38 Weeks
ERROR	30	156	117
REPLICATES	2	206	86
TREATMENTS	15	2606**	2350**
MAIN EFFECTS			
Soil	3	4493**	5360**
Residue	1	14502**	5874**
App. Soil N	1	4762**	3024**
INTERACTIONS			
Soil x Resi	3	1306**	3047**
Soil x Apps	3	257	320[X]
Resi x Apps	1	482[X]	11
S X R X A	3	393[X]	52

[X] and ** denote significance at P = 0.10 and 0.01, respectively.

LITERATURE CITED

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